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Why a Lotus Seven S4?

The Lotus Seven has become a true icon in the automotive world. With its combination of lightweight, simple design, and rigid chassis it has provided a benchmark to sports race cars over the years. Often “punching far above its weight” the Seven, even today, competes with the most expensive and highest technology products from some of the world’s largest automakers. Of the myriad of Seven derivatives made, the Series 4 (confusingly given the Type number 60 by Lotus) has been the least valued. With its fiberglass body in place of hand-paneled aluminum, and its 70’s style rather than the timeless shape of the Series 3, the S4 is often belittled as a sales disaster for Lotus. However, the S4 sold in greater numbers than previous sevens and brought a level of day-to-day driver comfort not seen before.

As an avid collector and racer of Lotus cars I have owned, driven, and raced a wide range of Types; however, the S4 Seven holds a special place in my heart. As a schoolchild I watched a local owner of a yellow S4 Seven drive to work every day. In sun, rain and even snow he drove with the top down with the exhaust announcing his passing. To this day I can see that car and even remember the damage to the front wing that the owner never got around to having fixed. But it didn’t matter, this was the car that defined excitement, it was the car that

started my interest in Lotus.

I have owned, rallied, and raced a 1969 Series 3 Seven for many years. It has undergone many modifications in its life but is now a dedicated race car ([\[link\]](#)). However, I miss the fun of driving a Seven on the street, and I have always wanted a S4. When a burnt out 1971 S4 was offered to me as a restoration project I jumped at the chance. After all, many of the components are the same as on my S3. Even the Ford 1600 cc crossflow is the same as in my S3 and Type 61 Formula Ford ([\[link\]](#)), so I had plenty of experience with those engines. In addition, almost every part is still available for the S4 making a restoration possible. I decided that a total restoration to create a period correct, but mechanically sound, Series 4 for street use was a great project.

The author's 1969 Series 3 Lotus Seven race car at Road Atlanta. Copyright: HSR.



The author's 1969 Lotus Type 61 Formula Ford race car at Road America. Copyright: Conceptcarz.com.



This book is aimed at documenting the stages of a complete automotive restoration. I would hope that by providing sources to all the components and processes, the reader would tackle their own restoration. As such it should also provide

information that restorers of vintage sports or race cars can find useful. It is also, in part, a history of the car and the concepts embedded in it. Finally, it is a journey towards a childhood dream.

Why Connexions?

Connexions was designed as a global repository of educational content. The entire collection is available free of charge, that anyone can access. In this regard, Connexions was one of the first initiatives in the field of open education. The idea is that the content can and should be shared, re-used and recombined, interconnected and continually enriched. This ability to continually update, add or correct the content offers significant advantages over traditional publication of educational and instructional text books.

Connexions contains materials at all levels and is organized in small units (called modules) that can be connected into larger collections (called courses). As a route for publishing technical guides Connexions excels. Each of the modules can be accessed by people interested in a single topic, while the Collection provides a complete story.

In attempting to create a comprehensive record of an automobile restoration and well as a future guide of its history, I chose Connexions as being the perfect route. Individual modules may be published as each section of the restoration work is accomplished allowing those interested to use the information long before the whole project is completed. I hope that more authors will seek to use the Connexions system as a route to instruction and

education in non-traditional areas.

Evolution

The Lotus Seven S3 predecessor to the S4. What was to be the “new Seven” evolved into the Europa S1. Mike Warner President of Lotus Components (a.k.a. Lotus Racing). Lotus Cars founder Colin Chapman (1928 - 1982).

The concept

In the mid sixties Lotus were trying to distance themselves from their kit-car heritage. The growing respectability of their productions cars (in particular the Elan) meant that a new class of customer was buying Lotus that didn't want to be associated with the Lotus Seven ([\[link\]](#)). As a consequence Lotus' founder, Colin Chapman, decided that there should be a replacement for the Seven. Given Lotus' on track success, it was reasonable that this new car should feature a mid-engine rear wheel drive design giving the customer a link to the highly successful F1 cars of the time. However, the resulting car, the Europa ([\[link\]](#)), was produced by the main Lotus Cars factory rather than by Lotus Components, the division responsible for the Seven.



In addition to the Seven, Lotus Components were responsible for the manufacture and sales of racing cars. Unfortunately, the race car business is highly seasonal, and as such Lotus Components needed to have a steady supply of income, and it was this role that the Seven filled. However, while other specialty race car manufacturers could be more flexible with

expenses during the off-season, Lotus Components had to provide its share of the corporate Group Lotus overhead, including such things as the company airplane. The President of Lotus Components at this time, Mike Warner ([\[link\]](#)), decided that rationalization and cost cutting was needed.



A detailed study of the manufacturing process of the Seven showed a number of areas that costs could be saved. This led to the development of the Series 3 Seven. However, Warner felt these savings did not go far enough. In particular each Seven lost about £100. Chassis a main cost, since it was complex and time consuming to make. Warner even tried to put more workers onto each Seven, but found they actually got in each other's way and slowed the

overall production rate. In addition to the cost issues, Warner believed there was a wider market for the Seven if it could be made more accessible to the sports car buyer, who may be ordinarily attracted to MG or Triumph. With all this information Warner went to Lotus founder Colin Chapman ([\[link\]](#)) and the Lotus Board with a proposal to rationalize the Seven. In 1969 Warner was given the green light for the Seven development.



The Type 60 Lotus Seven S4.

Development

To this day, it is not clear if Colin Chapman had any input to the design of the S4. Certainly, it is suggestive that he didn't given his shocked reaction in seeing the prototype. However, it has been suggested that it would be unlikely that he would

have known anything of its gestation. Chapman certainly had to approve the budget of given £5000 provided for the development program. Later, in 1978, Chapman admitted that “I was so busy with other things that I more or less left Mike Warner to run the business on his own and he did this as a sort of secret project out the back”.

Despite the uncertainty of Chapman’s knowledge, it is known that Warner had a false wall constructed in the Lotus Components workshop so that development could be undertaken without interruption. The development team was limited to Peter Lucas and Alan Barrett. Over a period of (appropriately) seven months they set about designing a car essentially from scratch while keeping the overall shape and concept of the Seven intact ([\[link\]](#)). The fact that despite its name (“Seven”) this was a new car is evident from the use of a new Type number (60) for the resulting car. In contrast, the second generation Elise retained the 111 type number even though it was dramatically different to the S1 model.



Unveiling

The first showing of the S4 was to the Lotus Board and various key employees in October 1969 in one of the hangers at the Lotus factory in Hethel. It is recorded that it was at this event that Chapman was heard to exclaim to his wife, “Christ, Hazel, they’ve built a new bloody car”.

Despite the shock of a new car, it was clear that Warner’s team had done a good job, and in spite of the unusual unveiling ceremony it was decided to productionize the car. Although as a result of this incident Chapman and Warner were not on speaking terms, Chapman did provide significant later input. Arriving at the same time to the factory one morning, Chapman looked at Warner’s S4 prototype

and said “Well I suppose if we’re going to build the bloody thing I’d better drive it.” Chapman proceeded to drive the S4 around the Hethel test track with Warner taking notes and immediately told Warner of “twenty five points we were already working on improving and ten others that we should have been”.

The Seven had an unveiled to journalists at the Grovesnor Hotel in London in February 1970. This event proved even more trying that the unveiling to the Board. Warner and Chapman got into an argument and Warner stormed out before the showing. As a result Chapman and Marketing Director Graham Arnold had to muddle through the presentation. The Seven S4 was unveiled to the public at the Geneva Motor Show in March 1970.

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Design Analysis

The design target of the Lotus Seven S4 (Type 60) was to aimed at meeting several requirements:

- Lower cost of production, in particular the chassis and the hand beaten aluminum panels.
- Reduce the time of manufacture from the 12 hours for the Series 3.
- Find a market to a wider owner base with improved driver comfort and weather protection.
- Compete with sports cars from major manufacturers, such as MG Midget and Triumph Spitfire
- Provide a first step on the ladder of Lotus ownership.
- Take advantage of the 1970's "beach buggy" craze.

The success of the design of the Seven S4, and the choice of various components, should be considered with regard to these goals. As such the S4 was a rather clever piece of design that largely overcame the cost problems of the Seven S3.

A cut-away drawing of the Twin Cam version of the Seven S4 showing the chassis and body components (Motor magazine). A later left hand drive S4 (designated by the front indicator lights integrated into the front wings) fitted with a Lotus Twin Cam as evidenced from the lack of a bulge on top of the

bonnet. Unusually, the steel chassis side panels are body colored rather than being painted black. A later model right hand drive Ford 1600 GT crossflow powered S4 with the front indicator lights integrated with the front wings and a bonnet bulge to clear the downdraft Weber's air filter.

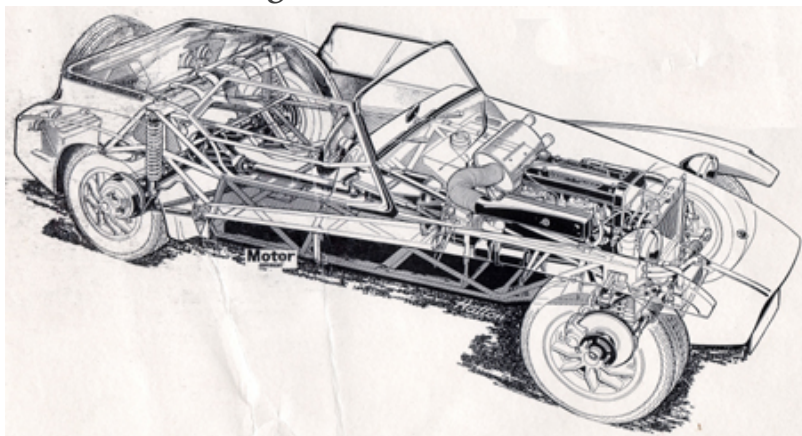
Chassis and body

Although the Peter Lucas designed chassis of the Type 60 Seven S4 is basically a mild steel tubular frame design, it is significantly simplified as compared to the preceding Seven models. Using steel square upper and lower side tubes with triangulation and cross members with square steel tubes, the main chassis was simple in design. A rear frame was made from round tubular steel. The upper rear chassis doubled as the attachment point for the 7½ gallon steel fuel tank, the seat belts, and the body to the chassis.

With the elimination of much of the triangulation used in the S2 and S3 models, the rigidity of the S4 was dependent on the presence of two welded side panels made of sheet steel. Further simplification and strength was provided by the front box section being made of folded steel rather than tubular in structure. This followed the fashion of the Lotus Elan and Europa models. A folded steel bulkhead panel was used in place of the usual tubular support. As with the previous Sevens, Arch Motors

fabricated the majority of chassis, although Griston Engineering produced some when Arch was too busy. This may account for the "GE-###" numbers stamped into some chassis.

The car's overall rigidity was also enhanced by the attachment of the body ([\[link\]](#)). Instead of the old stressed aluminum bodywork riveted to chassis that took many hours of skilled work to produce, the Series 4 used an Alan Barrett designed fiberglass body, consisting of four components: tub, bonnet, and two front wings.



The main tub comprised the boot, rear wings, interior, dash, and scuttle. The interior incorporated the floor and molding for the seat installation. The rear wings were much bulkier than on previous Sevens and extended further back. The main tub also incorporated moldings for the spare wheel bracket and the rear lights.

The body is attached to the chassis by six sets of

mounting bolts. In typical Lotus fashion many of the bolts serve multiple purposes. For example, the bolts that attach the body at the upper chassis rails are also used to locate the windscreen frames. The rear most chassis/body attachments are also used for the fuel tank and the seat belts, while the seat belts (or harnesses) are attached through the lower body and chassis. Finally, the rearmost chassis-to-body mounting is also used for the attachment of the upper trailing arm to the rear suspension.

There were several generations of bonnet used. Initially two were supplied depending on the choice of engine. Lotus Twin Cam powered cars had a flat bonnet with a bulge on the left hand side ([\[link\]](#)) to accommodate the twin Weber carburetors and the associated air box ([\[link\]](#)). Cars fitted with the Ford 1300 cc or 1600 cc crossflow Kent motors used a single down draft Weber carburetor, and their bonnets needed a bulge on top for clearance of the air filter ([\[link\]](#)). Later on a generic bonnet was designed that allowed either type of engine to be used.



While the Series 4 Seven's front wings were of the clamshell type first seen on the Seven America, as opposed to the cycle wing style favored by the Series 1 and 2 cars, the front wings extended all the way to the rear. The advantage of this design was that the passenger on right hand drive cars (see [\[link\]](#)) or the driver on left hand cars (see [\[link\]](#)) did not risk burning their ankles on the hot exhaust

while entering or exiting the car. The front wings were attached via bolts to the steel side panels. Support for the wings was by a curved steel stay.

The body panels were originally made from self-colored (pigmented) resin fiberglass composite. The color pigment was mixed with the gel coat. While this resulted in a simple finish it did limit the available colors and meant that many S4 Sevens were (or have been) repainted. The original colors included: white, red, light blue, yellow, bright orange, and the very seventies lime green. It should be noted that the self-coloring route predated the use of the technique in the Lotus Esprit of 1976.

The overall look of the Alan Barrett designed body was a cross between the traditional seven look and the type of beach buggy that was in vogue in the 1970's. Traditionalist bemoaned that the Seven had gone soft. However, one positive result of the new body was that the truly horrible aerodynamic efficiency of the Seven was improved. For example, the rear wings (fenders) were elongated giving a more egg-shape profile. The Series 2 and 3 Sevens (and the subsequent Caterham derivatives) are among the cars with the highest drag coefficients ($C_D = 0.6$). To put this in perspective, a family saloon routinely achieves a C_D of 0.3. While exact numbers are not known for the S4 it is considered a significant step in the right direction.

The suspension and steering

The front suspension

The front suspension of the Seven S4 uses the links, anti-roll (sway) bar, and bushes from the Lotus Europa. This had two advantages:

- 1. The parts were cheaper and readily available in the factory parts bin.
- 2. Abandoning the Lotus 12 type front suspension (in which the upper wishbone was actually comprised of a single top link and the anti-roll bar) meant that the Seven had a true double wishbone front suspension for the first time.

The uprights, also used in the Europa are originally Triumph in origin, as used in the Herald and Spitfire. The brake disks and calipers are also Triumph, but the hubs are of Ford origin and have a 4 1/4" stud pitch matching the Ford sourced rear axle. [\[link\]](#) lists a summary of the nut and bolts used in the front suspension of the Lotus Seven S4.

Application	Size
Upper wishbones, anti-	1/2" nyloc on threaded

roll (sway) bar link, and upper shock (damper) to chassis	pivot pin
Lower wishbones to chassis	1/2" nyloc
Lower wishbones to lower shock (damper)	1 1/2" x 2 1/2" & nyloc
Lower wishbones to trunnion	7/16" x 2 3/4" & nyloc

Selected list of nut and bolts used (in one side) the front suspension of the Lotus Seven S4.

The rear suspension

One of the drawbacks of the Series 3 Lotus Seven was the design of the rear suspension. Although effective, the A-arm location of the rear axle in the S3 was a weakness that led to several failures (especially cracked differentials) and required the axle to be significantly reinforced. In order to overcome this Peter Lucas designed a much simpler system for the Series 4. The ends of the Ford Escort live axle were located by leading (lower) and trailing (upper) radius arms of the Watts linkage type, while the location of axle was achieved with an axle-locating link attached to the left hand side lower radius arm. The lower radius arms were mounted on big rubber bushes to compensate for the conflicted geometry as a result of bumps that is inherent on this geometry. Without the bushings the

axle would act as an anti-roll (sway) bar. In this regard it was only partially successful since the inside wheel of the S4 is known to lift off the ground under hard cornering. [\[link\]](#) lists a summary of the nut and bolts used in the rear suspension of the Seven S4. The rear axle was given a 3.77:1 final drive ratio.

Application	Size
Lower radius arm to bushing	7/16" x 3"
Lower radius arm to axle	1/2" x 5"
Axle locating link to bushing	7/16" x 3"
Axle locating link to axle	1/2" x 5"
Axle locating link to center chassis mounting	1/2" x 5"
Upper radius arm to chassis	1/2" x 4" (per side)
Upper radius arm to axle	1/2" x 23/4" (per side)
Shock (damper) to axle	1/2" x 23/4" (per side)
Shock (damper) to chassis	1/2" x 3" with rounded nose (per side)

List of nut and bolts used for the rear suspension of the Lotus Seven S4.

Brakes

The front brakes were unchanged from the S3 Seven and used Girling trailing calipers. These were used in a wide range of British cars of the era (including the Triumph Spitfire), as well as many low budget formula cars, such as the Formula Fords. The brakes were hydraulically operated with 9" solid discs. The rear brakes are hydraulically operated 8 1/2" drums incorporating a mechanical handbrake.

Steering

The Triumph Spitfire rack used in the Series 3 Seven was replaced with one sourced from Burman. The turning circle remained excellent with 2 3/4 turns lock-to-lock. For the first time, the steering column was collapsible in a front impact as a safety feature.

The 1558 cc Lotus Twin Cam engine as used in the Seven S3 SS, Seven S4, Elan, Elan + 2, Europa Twin Cam, and Lotus Cortina (www.burtonpower.com). A cut away of the 1558 cc Lotus Twin Cam engine.

The Weber 40 DCOE sidedraught carburetor. The engine bay of a Twin Cam powered Seven S4 showing the air box. A cut-away drawing of the Twin Cam powered version of the Seven S4 with general technical data (Lotus Cars, Ltd.). The Ford Kent 1600 cc crossflow engine

(www.burtonpower.com). The Weber 32DFM twin choke downdraught carburetor. Copyright: Pegasus Auto Racing. The engine bay of a 1600 cc crossflow

powered Seven S4 showing the pancake air filter. This example is in need of restoration. The Ford Mark 2 Cortina GT/Corsair 2000E (2821E) gearbox (www.burtonpower.com).

Engine and transmission

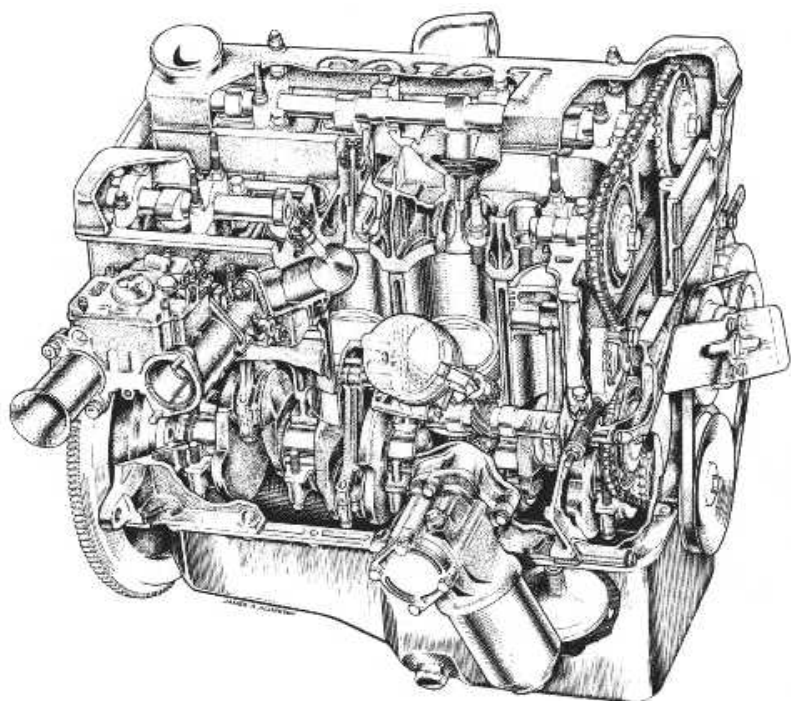
As with the preceding Series 3 Seven, the S4 was offered with a selection of engines. The 1558 cc Lotus Twin Cam was the performance choice while the budget (and consequently most common) choice was the 1600 cc Ford crossflow Kent motor. A third offering was the 1300 cc Ford crossflow Kent engine. Unfortunately, the sump for the latter engine had the oil pan at the rear of the sump, which forced one of the chassis cross members to be simply removed. A limited number of these were actually sold.

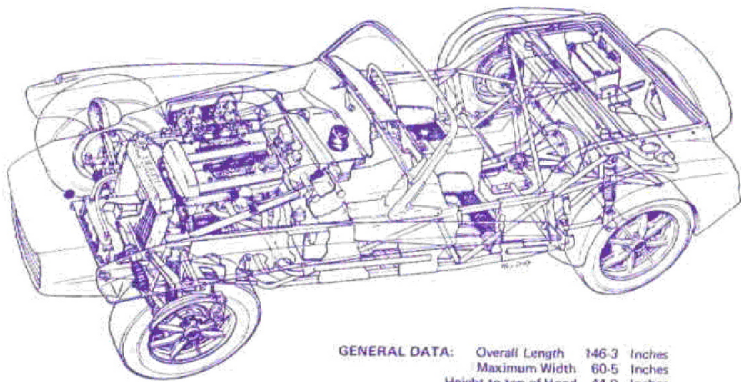
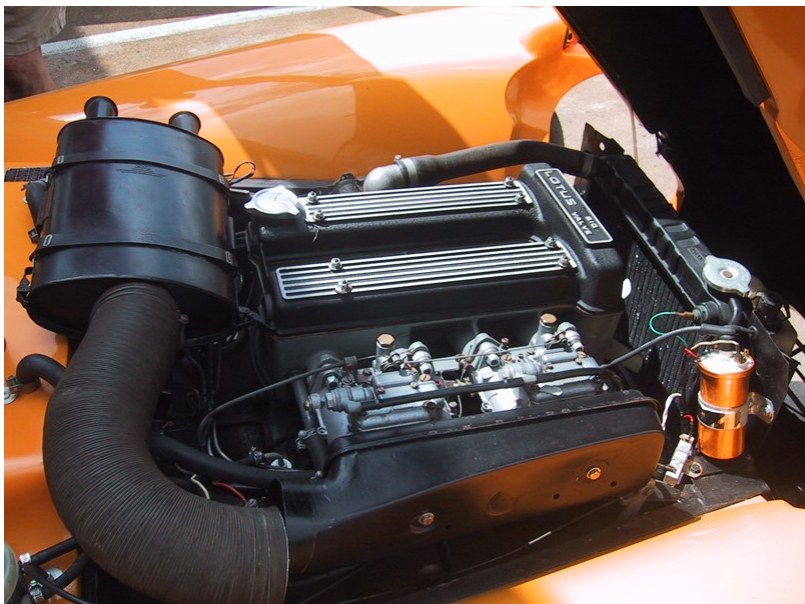
Lotus Twin Cam

The Lotus Twin Cam engine ([\[link\]](#) and [\[link\]](#)) was developed from the Ford 1498 cc 116E pre-crossflow engine block. Overbored and given a longer stroke crankshaft the capacity was raised to 1558 cc. Using twin Weber 40 DCOE carburetors ([\[link\]](#)) the Twin Cam model with 115 bhp in Special Equipment tune or as a Lotus-Holbay version 126 bhp ([\[link\]](#) and [\[link\]](#)). A summary of the specifications of the Special Equipment tune Twin

Cam engine is given in [\[link\]](#).







GENERAL DATA: Overall Length 146.3 Inches
Maximum Width 60.5 Inches
Height to top of Hood 44.0 Inches
Height to top of Screen 41.5 Inches
Front Track 48.8 Inches
Rear Track 51.5 Inches
Ground Clearance (under chassis) 6.5 Inches
Weight Laden (Twin-Cam Version) 1310 lbs.

Engine

Lotus Twin Cam Ford Kent (1600)

		GT)
Displacement (cc)	1558	1599
Bore (mm)	92.55	90.98
Stroke (mm)	72.74	77.62
Compression ratio	9.5:1 or 10.3:1	9.0:1
Power (bhp)	105 to 120	84 (110)
Torque (lbs/ft @ rpm)	108 @ 4500 (113 @ 5500)	91 @ 5500 (105.5 @ 4800)
Oil pressure	35 - 40	35 - 40
Valve clearances	In 0.005, Ex 0.009	In 0.010, Ex 0.022
Carburetor	Twin Weber 40 DCOE sidedraught	Single Weber 32DFM twin choke downdraught

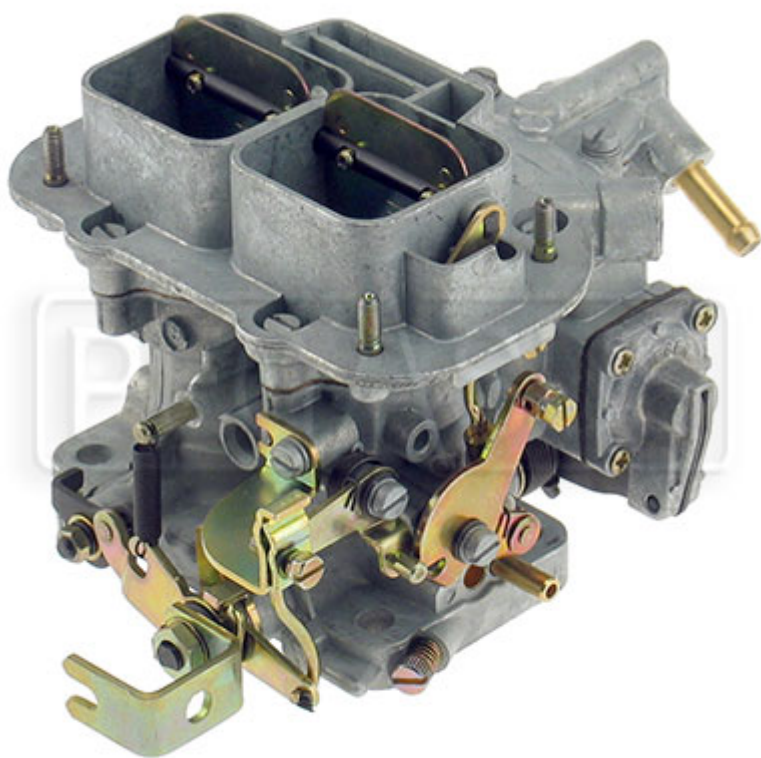
Summary of engines used in the Lotus Seven S4.

The Ford crossflow Kent

Ford introduced the 105E Kent engine in 1959 in a number of displacements: 997 cc, 1198 cc, 1340 cc, and 1500 cc. All of these early Kent engines had both inlet and exhaust valves on the same side of the head. In 1967 Ford redesigned the head as a crossflow unit creating the definitive 1300 cc and 1600 cc engines ([\[link\]](#)). In 1970 Ford further improved the block making it stronger and more suitable for tuning and racing applications. These

blocks are designated by their “711M” numbering. As used in the Seven the 1600 cc engine was essentially that from the Ford Cortina GT and used a standard Ford intake manifold with a single Weber 32DFM twin choke downdraught carburetor ([\[link\]](#) and [\[link\]](#)). A summary of the specifications of the Cortina GT tune Ford crossflow Kent engine are given in [\[link\]](#).





Gearbox, clutch, and bellhousing

As with the S2 and S3 Seven, the Ford Mark 2 Cortina GT/Corsair 2000E gearbox was employed. More correctly known as the 2821E, it is a semi-close ratio 4-speed all synchromesh gearbox ([\[link\]](#)), with synchromesh on all forward gears. Since it was also used in the Lotus Elan it meant a commonality of supply for Lotus Cars and Lotus Components.

Gear	Gear ratio
1	2.97 : 1
2	2.01 : 1
3	1.40 : 1
4	1 : 1
Reverse	3.32 : 1

Gear ratios for Ford 2000E Corsair gearbox as used in the Lotus Seven S4.

As fitted to the Seven (and Ford's own Corsair and Cortina) the gearbox was used with a separate remote control assembly ([\[link\]](#)). The three-rail selector mechanism was later replaced by a single selector rail; however, since this requires modification to be used in the Seven it was not

adopted.



The 2821E gearbox uses a separate bellhousing that is interchangeable between crossflow and Twin Cam engines because they have common bolt patterns. The flywheels and clutches are also interchangeable within the Kent range of engines. However, since the Crossflow power Seven S4 retained the bellhousing for the Twin Cam, it is necessary to fit an additional spacer for the release bearing.

A well-worn interior for a Lotus Seven S4. A view of the dash of a Seven S4.

Interior

The interior of the S4 was a great improvement over that of the S3 Seven. In particular it offered more space and allowed taller drivers to fit, although the pedals were still tight. The dashboard was either painted to give a leather grain finish, left in body color or sprayed matt black ([\[link\]](#)).



The seats were the same as fitted in the Europa, but without a headrest. They are made of hardboard covered in foam and black vinyl. In contrast to the bare metal finish of the S3 Seven, the S4 had a properly fitted black carpet and a vinyl transmission tunnel cover to match the seats ([\[link\]](#)).

The dashboard layout for the S4 included a full range of Smiths gauges ([\[link\]](#)), including:

- Speedometer.
- Tachometer.
- Oil pressure.
- Water temperature.
- Ammeter.
- Fuel gauge.

Four rocker switches controlled the lights, heater fan (optional), 2 speed windscreen wiper, and windscreen washer (optional), while the indicator switch and headlight dip switches were located in the “normal” position as storks on the steering column for the first time for a Seven. The horn push was located in the center of the steering wheel. The steering wheel was a 13” alloy spoke wheel (smaller than used in the S3) with PVC rim ([\[link\]](#)). The design was the same as used in the contemporary Elan and Europa.



A later Twin Cam powered S4, fitted with the universal bonnet incorporating a bonnet bulge, showing the side screens with the sliding Perspex windows. A Seven S4 fitted with the rare factory hard top.

Weather equipment

The weather equipment was one area that the S4 Seven came in for universal praise. While not offering complete drip-free driving (no Seven has ever achieved this), the roof offered reasonable weather protection. As designed by Weathershields of Birmingham the major improvement over previous Sevens was the fitment of sliding Perspex window panels ([\[link\]](#)). Another first for a Seven was the option of a stylish hardtop ([\[link\]](#)).



A view of the Brand Lotus wheels as fitted to the Seven S4.

Wheels and tires

The S4 Seven was provided standard with 5 1/2" x 13" pressed steel 'bolt-on' rims with chromium plated hub-caps ([\[link\]](#)). As an upgrade 5 1/2" x 13" light alloy 'bolt-on' Brand Lotus rims were available at extra cost ([\[link\]](#)). Both wheels were supplied with either 165 x 13" Dunlop SP Sport or Goodyear G800 radial tires as standard.



Dimensions

A summary of the dimensions of the Seven S4 is

given in [\[link\]](#).

Overall length	146.3"
Overall width	60.5"
Overall height (top of hood)	44.0"
Overall height (top of screen)	41.5"
Ground clearance	6.5"
Wheelbase	91.0"
Front track	49.9"
Rear track	51.5"
Ground clearance	6.5".
Front wheel toe in	0 1/16 "
Front camber angle	0°
Front caster angle	5°
Laden weight	1310 lbs (Twin Cam), 1276 lbs (1600 GT)
Weight distribution	56.1/43.9% (Twin Cam), 48.5/51.5% (1600 GT)

Summary of official dimensions for the Lotus (Type 60) Seven S4.

Performance

[\[link\]](#) summarizes the performance data from contemporary car magazine tests for both the Ford 1600 GT (crossflow) and Lotus Twin Cam powered cars.

<i>Test source</i>	<i>Motor</i>	<i>Car and Driver</i>	<i>Sports Car World</i>
Test date	1970	1971	1974
Engine	1600 GT	Lotus Twin Cam	Lotus Twin Cam
0 - 30 mph	3.0 sec	2.6 sec	3.0 sec
0 - 40 mph	4.5 sec	4.2 sec	5.0 sec
0 - 50 mph	6.3 sec	6.0 sec	6.7 sec
0 - 60 mph	8.8 sec	8.7 sec	8.8 sec
0 - 70 mph	11.8 sec	11.4 sec	11.4 sec
0 - 80 mph	16.0 sec	14.8 sec	15.0 sec
0 - 90 mph	24.2 sec	19.0 sec	21.2 sec
0 - 100 mph	n/a	24.5 sec	n/a
Standing ¼ mile	16.0 sec	15.8 sec	16.0 sec
Top speed	108.5 mph	116 mph	n/a
80-0 mph	n/a	247 ft (0.85 G)	n/a
Fuel mileage	26.3 mpg	14 - 16 mpg	n/a
Cruising range	n/a	105 - 120 miles	n/a

Selected performance figures for Lotus Seven S4
from contemporary magazine road tests.

Chassis numbering

The initial batches of the Lotus Seven S4 were built by Lotus Components and started with the chassis number S4/2650. Subsequent to the winding down of Lotus Components, the cars were built by the main Lotus Cars factory. Left hand drive cars were given the prefix *LBS4* or *LS4*. The total number is uncertain since there appears to be a gap in the chassis numbering between 3238 and 3299. Upon transfer of production to Caterham cars thirty seven cars were built; however, Caterham assembled most of these from Lotus leftover cars rather than new manufacturing.

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Production

A representative example of the marketing approach for the more user-friendly Seven S4. A copy of a Seven S4 price list in pre-decimalization currency (pounds, shillings, and pence). Copyright: Lotus Cars, Ltd.

Marketing

Mike Warner, the head of Lotus Components (later renamed Lotus Racing) believed that the market for the Seven should fit into a graduated range. The idea being that a young car buyer would get a Seven, then as their income increased they would trade-up to an Elan, and finally with the advent of a family the Elan + 2. While Colin Chapman, the founder of Lotus, did not share this view, every S4 Seven was sold with a windshield sticker reading “Lotus Motoring Begins Here”.

As part of Warner’s strategy he persuaded Chapman to allow the Seven to be marketed by Lotus Racing (Components) as opposed to corporate Lotus Sales. With this control, he created a glamorous series of adverts ([\[link\]](#) and [\[link\]](#)), including creating replicas of the Lotus Elan advertisements shown outside a fashionable London nightclub, Annabel’s.



lotus seven

Model Range

1600 G.T. Basic	945-0-0
1600 S/E De Luxe	995-0-0
Lotus Holbay "Clubman"	1295-0-0
Lotus Twin Cam	1245-0-0

Standard Specification on Basic Model includes - ☐ 1. Roll over Bar ☐ 2. P.V.C. Facia ☐ 3. Boot Area Black Finish ☐ 4. Trimmed Armrest C/W Ashtray ☐ 5. Wings Undersealed ☐ 6. Laminated Windscreen.

De-Luxe Specification includes items 1 to 6 on the Basic Model, and also - Stage II Assembly, 2000E Semi-Close Ratio Gearbox, 4 Branch Exhaust System.

Optional Extras

2000E Semi-Close ratio gearbox	25	0	0
4 branch exhaust system	16	0	0
Stage II Assembly	18	7	6
Screen Washer	3	5	0
Heater Kit complete	17	0	0
Air Horns	5	17	10 Set
Repeater Flasher	12	6	Each
Roll-over bar	15	0	0
Tonneau Cover	10	0	0
Brand Lotus Alloy Wheels	12	8	6
Tool Roll	5	12	6
Interior Map Reading Lamp	1	12	7
Lap & Diagonal seat belts fitted to all models as an extra	6	6	0
Hard Top	65	0	0
Full Harness Seat Belts	4	16	0

Prices refer to Component Form only and together with the specification are liable to change without prior notice.



In another departure from previous Seven models,

the S4 was sold through a separate distribution network. Caterham Cars had been the sole distributor for the Seven for some years, and had been responsible for placing enough orders to keep the Seven in production. However, Warner also appointed six additional Lotus dealers to sell the Seven. Exact figures are unknown, however, it is clear that these new dealerships only accounted for a fraction of the total sales.

Sales

It is a common misconception that the S4 was a sales disaster. It is true that production never reached the lofty goals of 2,000 per year set by Mike Warner. In the best week of production 15 kits were shipped; however, the average was closer to 4 per week. Nevertheless, as may be seen from the data in [\[link\]](#), the annual sales figures were twice that of the S3, the model that has gained iconic status. Thus, in its time the Seven S4 was a sales success for Lotus Components. One area that the S4 did not achieve sales success was the export market, in particular the US. Because the car was never federalized, it had to be imported as a ‘grey’ market car, most often in kit form.

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Model	Years of production	Number manufactured	Number/year (calculated)
S1	1957 - 1960	243	60
S2	1960 - 1968	1310	145
S3	1968 - 1970	350	116
S4	1970 - 1972	625	208

Summary of production figures for the Lotus Seven S1 - S4.

Finally, it is worth noting that while the Series 3 Seven lost Lotus Components between £100 and £110 per car, the S4 made a profit of £150 per car. This in itself is an achievement given the specialty nature of the Seven and the constraints within Group Lotus.

Reviews

In the March 12th 1970 issue of *Autocar* a preview of the car was presented. The reviewers noted “a lot of points we criticized have now been improved” and that the body “looks much more modern”. The design of the bonnet came in for praise since it “greatly improving engine accessibility”. When *Autocar* finally published a full report of the S4 1600 GT powered car in February 1973, they still liked it, although pointed out that there was a “free passage of wind through the car” and that snow was

known to get in the car. The long-term test car was stolen for its engine (!) so the reviewer upgraded to a Twin Cam powered car and suggested that the weather protection had improved.

In July 1970 *Motor Sport* published a review involving a drive from the Lotus factory at Hethel to Radnorshire in Wales. The car they used was actually Mike Warner's own Cortina GT model with 527 miles on the clock. The newness of the car was blamed for a very stiff gear change with third being "impossibly balky". Interestingly, they noted that the power bulge on the bonnet causes reflection of the sun. This was not something ever noted elsewhere, but perhaps they had a sunny day. Unusually, the seats also received some criticism. However, overall the car was described as civilized, and the finish of the fiberglass was described as "excellent". It is interesting that the fuel mileage recorded during the journey was 30 mpg (which equates to 25 mpg for US gallons).

Custom Car review of the Seven focused on the evolution of the Seven. In general they found it to be a sensible update, and liked the "vaguely razor edge styling"; however, two major grumbles were that the visibility in the rear view mirror, which gave a view of the top of the spare wheel, and the handbrake. This latter was a sentiment expressed by many reviewers because the position above the drivers knee.

Given that one of the design targets of the Lotus Seven S4 was to take advantage of the 1970's "beach buggy" craze, it is interesting that *Car* magazine published a comparison test of the S4 with a Mantra Ray beach buggy and the three-wheel psychedelic orange Bond Bug 700 ES. In this group test, the Seven was described as the "most normal", not something that has possibly ever been said before or since about a Seven.

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The Car When New

The Lotus Seven S4 was originally bought 50/50 by college friends Nelson Briceno and Alan Beagle. According to Lotus records this particular car LBS4/2894/GT left the factory in Norwich configured with a 1600 cc Ford crossflow engine, a Ford standard gearbox and was red. The car was shipped as a kit direct to the US, in November 1970, but not registered until 1971.

The following show the subject of the restoration project when it was new. All the photographs are courtesy of Deana Briceno. [\[link\]](#) shows a view of the car with soft top roof (hood) stowed. The original bright orange/red paint looks muted in the photograph, but the black painted chassis and black interior are clear. [\[link\]](#) shows a front quarter view with the car with the soft top (hood) and side screens in place being flanked by the original co-owners. The addition of a black nose ring and center stripe are evident. [\[link\]](#) shows a clearer view of the car with Alan Beagle and a friend. The position of the wing mirrors and the addition of stone-chip guard on the rear wing (fender) may be seen. The final photograph ([\[link\]](#)) shows Nelson struggling with the rear clips of the roof. It is interesting to note the addition of a checkered flag motif on the right rear wing.

The 1971 Lotus Seven S4 when new.



The Seven with the original co-owners: Alan Beagle (left) and Nelson Briceno (right).



The Seven with original co-owners Alan Beagle (right).



A rear view of the car with Nelson Briceno, showing the unusual checkered flag pattern on the right rear wing.



Stripping the Remains and Assessing the Damage

Introduction

In the study of electrochemistry, it had always been a challenge to obtain immediate and continuous detection of electrochemical products due to the limited formation on the surface of the electrode, until the discovery of differential electrochemical mass spectrometry. Scientists initially tested the idea by combining porous membrane and mass spectrometry for product analysis in the study of oxygen generation from HClO_4 using porous electrode in 1971. In 1984, another similar experiment was performed using a porous Teflon membrane with 100 μm of lacquers at the surface between the electrolytes and the vacuum system. Comparing to previous experiment, this experiment has demonstrated a vacuum system with improved time derivative that showed nearly immediate detection of volatile electrochemical reaction products, with high sensitivity of detecting as small as “one monolayer” at the electrode. In summary, the experiment demonstrated in 1984 not only showed continuous sample detection in mass spectrometry but also the rates of formation, which distinguished itself from the technique performed previously in 1971. Hence, this method was called differential electrochemical mass spectrometry

(DEMS). During the past couple decades, this technique has evolved from using classic electrode to rotating disc electrode (RDE), which provides a more homogeneous and faster transport of reaction species to the surface of the electrode.

Described in basic terms, differential electrochemical mass spectrometry is a characterization technique that analyzes specimens using both the electrochemical half-cell experimentation and mass spectrometry. It uses non-wetting membrane to separate the aqueous electrolyte and gaseous electrolyte, which gaseous electrolyte will permeate through the membrane and will be ionized and detected in the mass spectrometer using continuous, two-stage vacuum system. This analytical method can detect gaseous or volatile electrochemical reactants, reaction products, and even reaction intermediates. The instrument consists of three major components: electrochemical half-cell, PTFE (polytetrafluoroethylene) membrane interface, and quadrupole mass spectrometer (QMS), which is a part of the vacuum system.

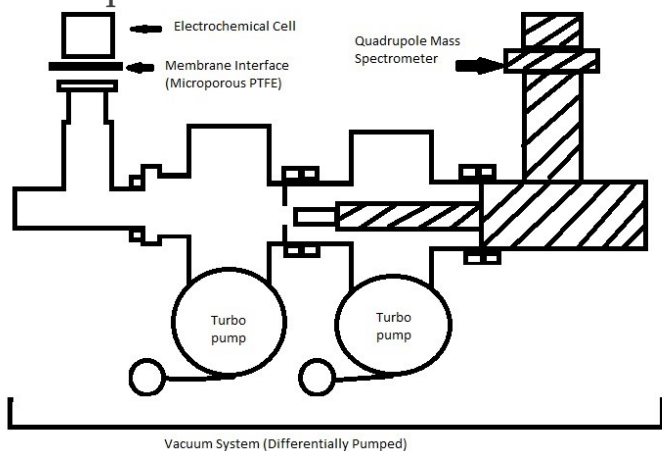
Mechanical setup of the entire differential electrochemical mass spectrometry. Adapted from Aston, S.J., “Design, Construction and Research Application of a Differential Electrochemical Mass Spectrometer (DEMS)”, Springer, 2011, 9-27. Mechanical assembly of electrochemical half cell. Figure adapted from J. S. Aston, *Design, Construction*

and Research Application of a Differential Electrochemical Mass Spectrometer (DEMS), Springer-Verlag, Berlin Heidelberg (2011). A illustration of the vacuum membrane distillation process. Adapted from J. S. Aston, *Design, Construction and Research Application of a Differential Electrochemical Mass Spectrometer (DEMS)*, Springer-Verlag, Berlin Heidelberg (2011). Chemical structures of polytetrafluoroethylene (PTFE), polypropylene and polyvinylidene fluoride (polyvinylidene difluoride, PVDF).

DEMS operations

The entire assembly of the instrument is shown in [\[link\]](#), which consists of three major components: an electrochemical half-cell, a PTFE membrane interface, and the quadrupole mass spectrometer. In this section, each component will be explained and its functionality will be explored, and additional information will be provided at the end of this section. The PTFE membrane is micro-porous membrane that separates the aqueous electrolyte from volatile electrolyte which will be drawn to the high vacuum portion. Using the high vacuum suction, the gaseous or volatile species will be allowed to permeate through the membrane using differential pressure, leaving the aqueous materials on the surface due to hydrophobic nature of the membrane. The selection of the membrane material is very important to maintain both the

hydrophobicity and proper diffusion of volatile species. The species permeated to QMS will be monitored and measured, and the kinetics of formation will be determined at the end. Depending on the operating condition, different vacuum pumps might be required.



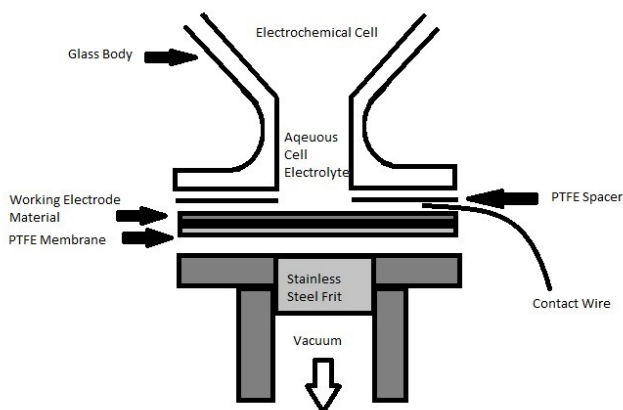
Electrochemical Cells

First major component of the DEMS instrument is the design of electrochemical cells. There are many different designs that have been developed for the past several decades, depending on the types of electrochemical reactions, the types and sizes of electrodes. However, only the classic cell will be discussed in this chapter.

DEMS method was first demonstrated using the classical method. A conventional setup of electrochemical cell is showed in [\[link\]](#). The powdered electrode material is deposited on the

porous membrane to form the working electrode, shown as Working Electrode Material in [\[link\]](#). In the demonstration by Wolber and Heitbaum, the electrode was prepared by having small Pt particles deposited onto the membrane by painting a lacquer. It was later in other experimentations evolved to use sputtering electro-catalyst layer for a more homogenous surface. The aqueous cell electrolyte is shielded with an upside down glass body with vertical tunnel opening to the PTFE membrane. The working electrode material lies above the PTFE membrane, where it is supported mechanically by stainless steel frit inside vacuum flange. Both the working electrode material and PTFE membrane are compressed between vacuum castings and PTFE spacer, which is a ring that prevents the electrolyte from leakage. The counter electrode (CE) and reference electrode (RE) made from platinum wire are placed on top of the working electrode material to create the electrical contact. One of the main advantages of the classical design is fast response time, with high efficiency of “0.5 for lacquer and 0.9 with the sputter electrode”. However, this method poses certain difficulties. First, the electrolyte materials will be absorbed on the working electrode before it permeates through the membrane. Due to the limitation of absorption rate, the concentration on the surface of the electrode will be lower than bulk. Second, the aqueous volatile electrolyte must be absorbed onto working electrode, and then followed by evaporation

through the membrane. Therefore, the difference in rates of absorption and evaporation will create a shift in equilibrium. Third, this method is also limited to the types of material that can be deposited on the surface, such as single crystals or even some polycrystalline electrode surfaces. Lastly, the way RE is position could potentially introduce impurity into the system, which will interfere with the experiment.



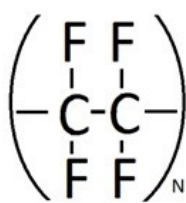
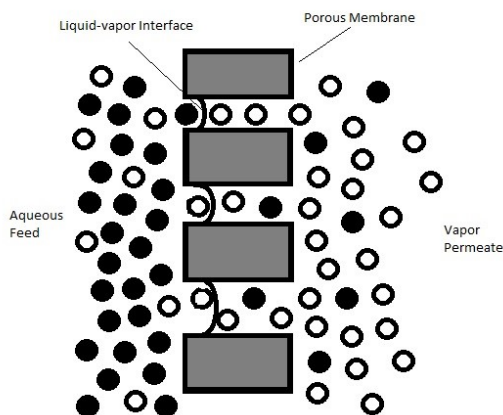
Membrane interface

PTFE membrane is placed between the aqueous electrolyte cell and the high vacuum system on the other end. It acts as a barrier that prevents aqueous electrolyte from passing through, while its selectivity allows the vaporized electrochemical species to transport to the high vacuum side, which the process is similar to vacuum membrane distillation shown in [\[link\]](#). In order to prevent the aqueous solution from penetrating through the

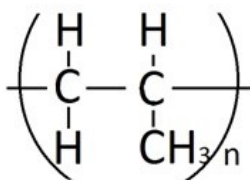
membrane, the surface of the membrane must be hydrophobic, which is a material property that repels water or aqueous fluid. Therefore, at each pore location, there is vapor and liquid interface where the liquid will remain on the surface while the vapor will penetrate into the membrane. Then the transportation of the material in vapor phase is triggered by the pressure difference created from the vacuum on the other end of the membrane.

Therefore, the size of the pore is crucial in controlling its hydrophobic properties and the transfer rate through the membrane. When the pore size is less than $0.8\text{ }\mu\text{m}$, the hydrophobic property is activated. This number is determined by calculating the surface tension of liquid, the contact angle and the applied pressure. Therefore, a membrane with relatively small pore sizes and large pore distribution is desired. In general membrane materials used are “typically $0.02\text{ }\mu\text{m}$ in size with thickness between 50 and $110\text{ }\mu\text{m}$ ”. In terms of materials, there are other materials such as polypropylene and polyvinylidene fluoride (PVDF) ([\[link\]](#)) have been tested; however, PTFE material ([\[link\]](#)) as membrane has demonstrated better durability and chemical resistance to electrochemical environment. Therefore, PTFE is shown to be the better candidate for such application, and is usually laminated onto polypropylene for enhanced mechanical properties. Despite the hydrophobic property of PTFE material, a significant amount aqueous material penetrates

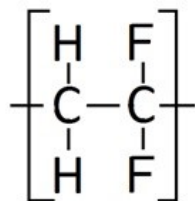
through the membrane due to the large pressure drop. Therefore, the correct sizing of the vacuum pumps is crucial to maintain the flux of gas to be transported to the mass spectrometry at the desired pressure. More information regarding the vacuum system will be discussed. In addition, capillary has been used in replacement of the membrane; however, this method will not be discussed here.



PTFE



Polypropylene



PVDF

Vacuum and QMS

The correctly sized vacuum system can ensure the maximum amount of vapor material to be transported across the membrane. When the pressure drop is not adequate, part of the vapor

material may be remain on the aqueous side as shown [\[link\]](#). However, when the pressure drop is too large, too much aqueous electrolyte will be pulled from the liquid-vapor interface, subsequently increasing load on the vacuum pumps. In the cases of improper sized pumps can reduce pump efficiency and lower pump life-time if such problem is not corrected immediately. In addition, in order for mass spectrometry operate properly, the gas flux will need to maintain at a certain flow. Therefore, the vacuum pumps should provide steady flux of gas around 0.09 mbar/s.cm² consisting mostly with gaseous or volatile species and other species that will be sent to mass spectrometry for analyzing. In additional, due to the limitation of pump speed of single vacuum pump, vacuum system with two or more pumps will be needed. For example, if 0.09 mbar/s.cm² is required and pump speed of 300 s⁻¹ that operates at 10⁻⁵ mbar, the acceptable membrane geometrical area is 0.033 cm⁻². In order to increase the membrane area, addition pumps will be required in order to achieve the same gas flux.

Additional information

There are several other analytical techniques such as cyclic voltammetry, potential step and galvanic step that can be combined with DEMS experiment. Cyclic voltammetry can provide both quantitative and qualitative results using the potential dependence. As a result, both the ion current of interested species

and faradaic electrode current (the current generated by the reduction or oxidation of some chemical substance at an electrode) will be recorded when combining cyclic voltammetry and DEMS.

CV for the alkaline MEA are shown with 0.1 M EtOH solution in (a) for only de-ionized water in analyte (a1) both at 60 °C. Adapted from V. Rao, Hariyanto, C. Cremers, and U. Stimming, *Fuel Cells*, 2007, 5, 417.

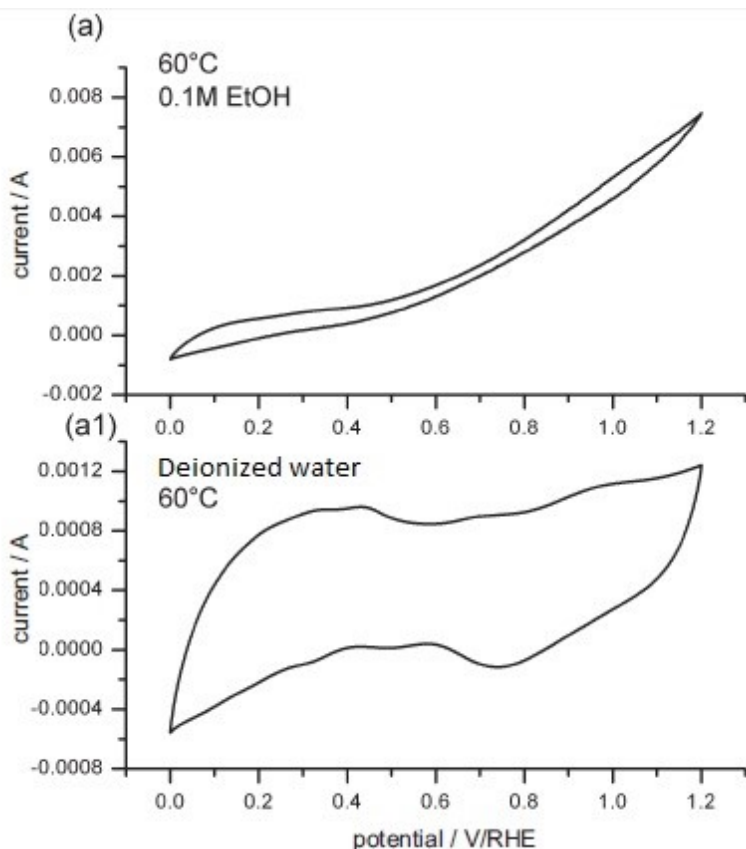
Applications

The lack of commercialization of this technique has limited it to only academic research. The largest field of application of DEMS is on electro-catalytic reactions. In addition, it is also used fuel cell research, detoxification reactions, electro-chemical gas sensors or more fundamental relevant research such as decomposition of ionic liquids etc.

Fuel cell differential electrochemical mass spectrometry: ethanol electro-oxidation

The ethanol oxidation reaction was studied using alkaline membrane electrode assemblies (MEAs), constructed using nanoparticle Pt catalyst and alkaline polymeric membrane. DEMS will be use to study the mechanics of the ethanol oxidation reaction on the pt-based catalysts. The relevant products of the oxidation reaction are carbon

dioxide, acetaldehyde and acetic acid. However, both carbon dioxide and acetaldehyde has the same molecular weight, which 44 g/mole. One approach is to monitor the major fragments where ionized CO_2^{2+} at $m/z = 22$ and COH^+ at $m/z = 29$ were used. Differential electrochemical mass spectrometry can detect volatile products of the electrochemical reaction; however, detections can be varied by solubility or boiling point. CO_2 is very volatile, but also soluble in water. If KOH is present, DEMS will not detect any CO_2 traces. Therefore, all extra alkaline impurities should be removed before measurements are taken. The electrochemical characteristics can also be measured under various conditions and examples shown in [\[link\]](#). In addition, the CCE (CO_2 current efficiency) was measured under different potentials. Using the CCE, the study concluded that the ethanol undergoes more complete oxidation using alkaline MEA than acidic MEA.



Studies on the decomposition of Ionic liquids.

Ionic liquids (IL) have several properties such as high ionic conductivity, low vapor pressure, high thermal and electrochemical stability, which make them great candidate for battery electrolyte.

Therefore, it is important to have better understanding of the stability of the reaction and of the products formed during decomposition behavior. DEMS is a powerful method where it can provide online detection of the volatile products;

however, it runs into problems with high viscosity of ILs and low permeability due to the size of the molecules. Therefore, researchers modified the traditional setup of DEMS, which the modified method made use of the low vapor pressure of ILs and have electrochemical cell placed directly into the vacuum system. This experiment shows that this technique can be designed for very specific application and can be modified easily.

Conclusion

DEMS technique can provide on-line detection of products for electrochemical reactions both analytically and kinetically. In addition, the results are delivered with high sensitivity where both products and by-products can be detected as long as they are volatile. It can be easily assembled in the laboratory environment. For the past several decades, this technique has demonstrated advanced development and has delivered good results for many applications such as fuel cells, gas sensors etc. However, this technique has its limitation. There are many factors that need to be considered when designing this system such as half-cell electrochemical reaction, absorption rate and etc. Due to these constraints, the type of membrane should be selected and pump should be sized accordingly. Therefore, this characterization method is not one size fits all and will need to be modified

base on the experimental parameters. Therefore, next step of development for DEMS is not only to improve its functions, but also to be utilized beyond the academic laboratory.

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Chassis Restoration

The Seven S4 (Type 60) chassis is actually comprised of a tubular structure reinforced by two sheet steel side panels that are spot-welded along the side and underside of the chassis. Once the chassis was stripped it was clear that there were signs of corrosion of the side lower tube below the sheet panel. Removal of both panels ([\[link\]](#)) showed only surface corrosion at this location. However, one of the upper side tubes was significantly corroded in the region of the engine bay and this had led to a 1/2" length hole. In addition to chassis lower tube the front box section had corroded resulting in the destruction of a significant portion of the lower half ([\[link\]](#)).

A view of the right hand side of the bare chassis.



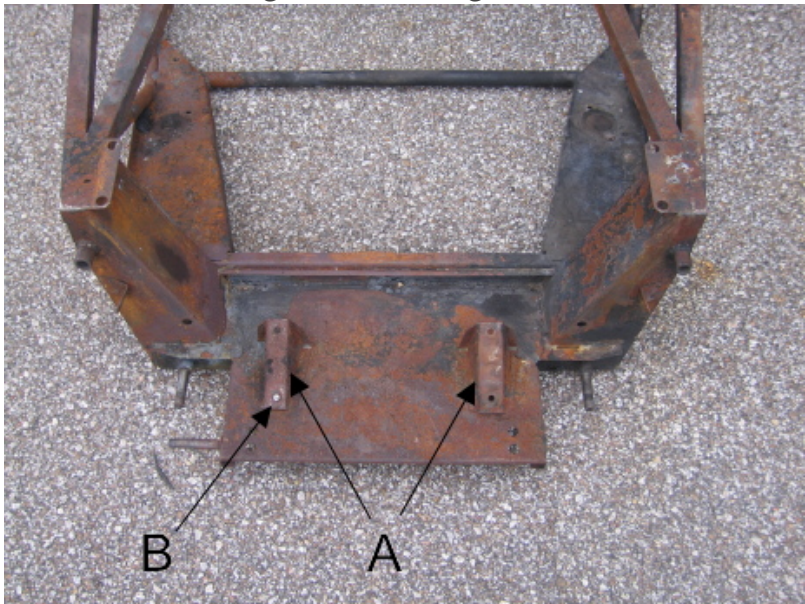
Underside of front box section before media blasting showing significant corrosion.



Three of the four bolts holding the two steering rack clamps were readily loosened; however, the last (forward right hand side) sheered-off ([\[link\]](#)) and will have to be drilled out.

The front box section and steering rack mounting

brackets (A) showing the single bolt (B) that sheered off while removing the steering rack.



The bare chassis after media blasting. An example of the bronze welding used in the chassis construction. Underside of front box section after media blasting for comparison with [\[link\]](#). The upper right side tube showing a hole due to corrosion. FIGURE. Schematic of the process for repair of the upper tubes. The upper right side tube showing the repair section in comparison with [\[link\]](#). The lower right side tube showing the repair section in comparison after welding, grinding and painting with primer. The upper left side engine brace tube showing the repair section after welding, grinding and painting with primer. View of lower left-hand side chassis tube showing removal of the section aft of the chassis-to-body bobbin. Schematic representation of the repair of lower chassis tube.

Finished repair lower chassis section. N.B. The chassis is upside down and thus viewed from below. Schematic of the reinforcement (shaded) added to the front box section. View of the underside of front box section (viewed from the front of the chassis) after removal of the old metal and welding in the lower plate. Compare with [\[link\]](#). View of the underside of front box section (viewed from the rear of the chassis) after removal of the old metal and welding in the lower plate. Compare with [\[link\]](#). The replacement steering rack mounting brackets. Compare to [\[link\]](#). Strengthening of the brackets on the rear cross member.

Repair of chassis

All chassis repairs were undertaken by Lucas Racing and Restoration (Houston, TX). In order to ascertain whether there was any additional damage hidden by corrosion, the chassis was cleaned by Custom Coatings (Cypress, TX) using media (alumina) blasting ([\[link\]](#)). Importantly, the bronze welding used on the chassis showed no sign of damage due to either age or the fire ([\[link\]](#)).





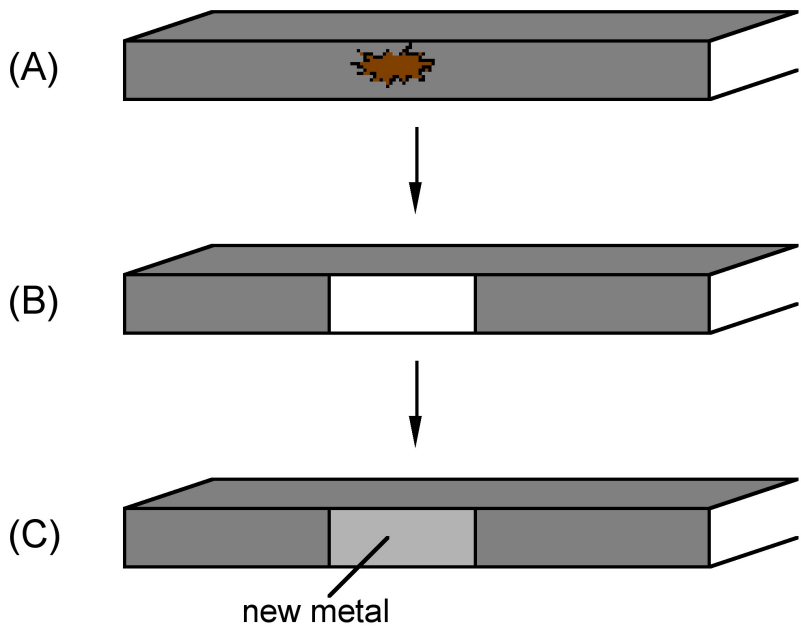
As expected the front box section will have to be replaced ([\[link\]](#)). Happily, the only damage due to corrosion in the steel tubing appeared to be in the upper right side tube, the lower left and right sides. In addition, it was found that one of the upper engine cross members was cracked.





Repair of side tubes

The first issue was to make a jig to ensure that the chassis frame remains straight during repair. As such it was found that there was a slight bend in the chassis frame that will be straightened during repair. The small sections of the right side upper and lower tubes were repaired by cutting out a small area from the damaged face ([\[link\]](#)) and welding in a replacement section ([\[link\]](#) and [\[link\]](#)). A similar process was used for the engine upper member ([\[link\]](#)).

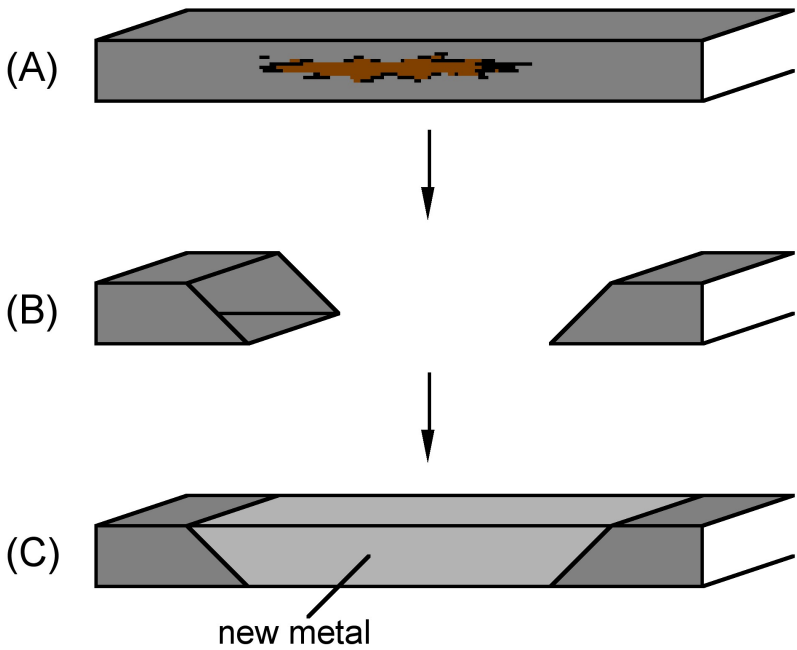




The lower left side required two separate sections to be replaced either side of one of the body-to-chassis threaded bobbins ([\[link\]](#)). One small section was removed in a similar manner to done for the upper

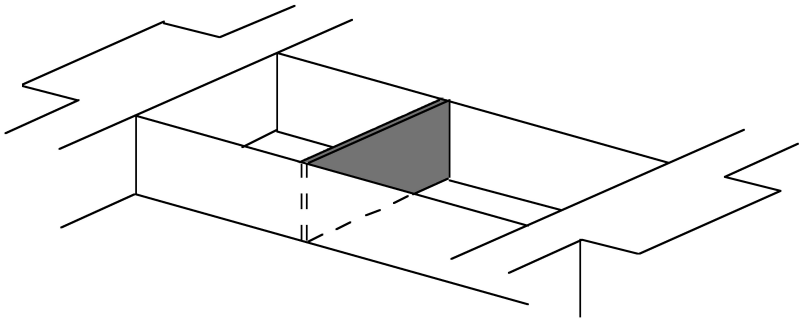
tubes ([\[link\]](#)) then a new piece of steel welded in-place. The second, larger, section was cut out completely rather than just one face of the tube. Furthermore, it was cut at an angle rather than at 90° to the tube ([\[link\]](#)) in order to provide larger welding area. The finished section is shown in [\[link\]](#).





Repair of front box section

The front box section is almost completely corroded and needs to be replaced. In addition, this is a good time for it to be strengthened so that it can be used as a front jack point. The complete lower part of the box was cut away and a replacement section made from 1/8" steel plate. Before the lower section is welded in place a brace is welded to strength the box ([\[link\]](#)). Once the lower section is welded in place the sides are straightened and then welded to the new metal ([\[link\]](#) and [\[link\]](#)).





On the upper side of the box section the seams were bronzed to ensure that no water ingress could occur and cause a repeat of the corrosion that was present.

Steering rack mount

As shown in [\[link\]](#) one of the four bolts holding the steering rack clamps had sheered-off. Given that the nut is welded to the lower side of the mount, and it was found difficult to remove the bolt or replace that one nut, it was decided to replace the whole top of the bracket along with new nuts ([\[link\]](#)).



Chassis brace

At the rear of the chassis the inner seat belt and axle locating link are attached to a removable brace. The points where this is bolted to the cross member were strengthened ([\[link\]](#)).

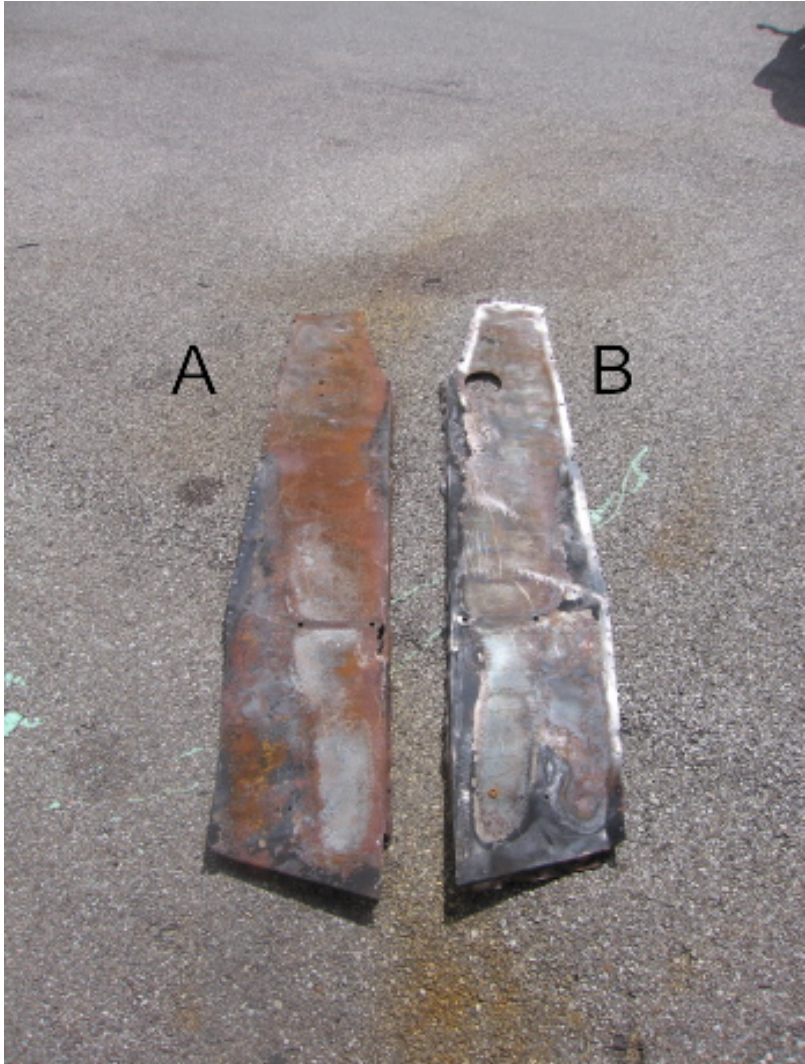


The outside of the two chassis panels of the Lotus Seven S4 after removal from the chassis. The panel from the right hand side of the car (A) shows more external corrosion, while the exhaust outlet is shown in the panel from the left hand side of the car (B). Note that the lower edges of the panels are facing each other. The chassis ready for powder coating, viewed from the front. The chassis ready for powder coating, viewed from the right hand side, and showing the new side panels. The chassis ready for powder coating, viewed from the rear, and showing the new side panels. Schematic representation of the alignment of the side panel with the lower chassis tube in the original (A) and replacement (B).

Fabrication and attachment of new side

panels

The original side panels were made from thin steel, and since they were damaged by the fire ([\[link\]](#)) it was necessary to replace the panels. However, it was decided to upgrade the thickness of the panel for added strength.

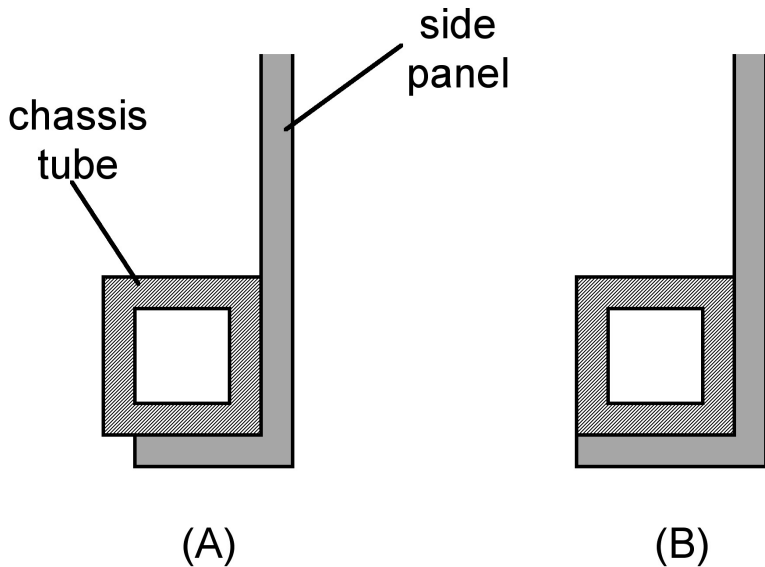


New panels were cut from 18 gauge steel using the original panels as templates. The new panels were welded to the repaired frame by drilling a 3/16" hole in the panel and TIG welding through the hole. This resulted in a spot-welded look, but with a greater strength. The finished panels are shown in [\[link\]](#) - [\[link\]](#). The original panels were sized such that when the edges were folded over the chassis rail, they did not meet the edge ([\[link\]](#)A). The new panels were sized such that the edges matched ([\[link\]](#)B). Prior to welding the side panels, the chassis and panels were sprayed with weld-through primer to ensure that corrosion does not occur under the powder coat.









Powder coated chassis viewed from the front.
Powder coated chassis viewed from the right.
Powder coated chassis viewed from the left. Powder coated chassis viewed from the rear. Powder coated engine bay viewed from the left (intake side of the engine). Powder coated engine bay viewed from the right (exhaust side of the engine). Powder coated chassis brace and the rear cross member. View of the frame number stamped onto the right hand side scuttle.

Cleaning and powder coatings

Once the chassis frame was repaired and the new side panels were welded in place the whole chassis was cleaned by media blasting and powder coated semi gloss black ([\[link\]](#) - [\[link\]](#)). Powder coating was performed by Custom Coatings (Cypress, TX).

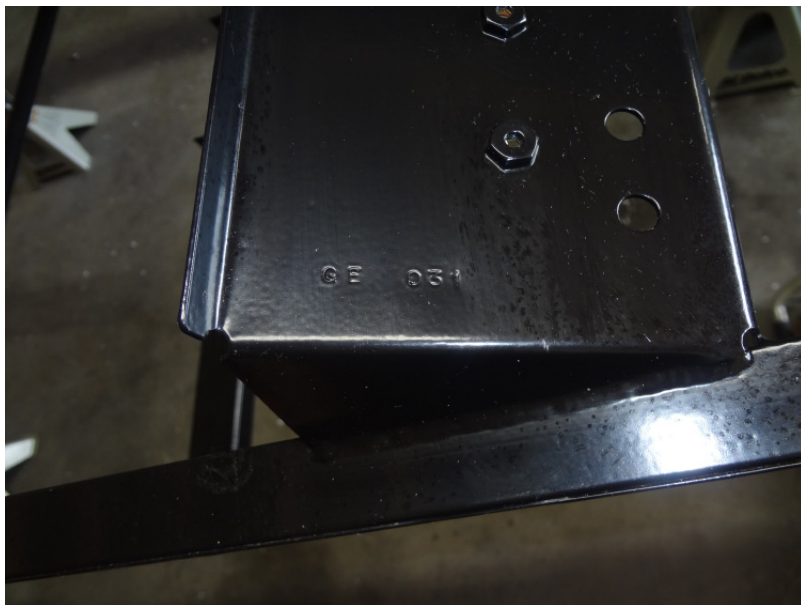








One of the advantages of media blasting and powder coating is that the original frame number became visible ([\[link\]](#)). The number GE-031 indicates that the chassis was produced by Griston Engineering.



Resources

- Lucas Racing and Restoration, 10030 Talley Lane, Houston, TX 77041, USA Tel: +1 713 462 0068. www.lucasracinginc.com.
- Custom Coatings, 16219 Dundee, Cypress, TX 77429, USA. Tel: +1 281 813 0119.

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Mercian Press (1987).

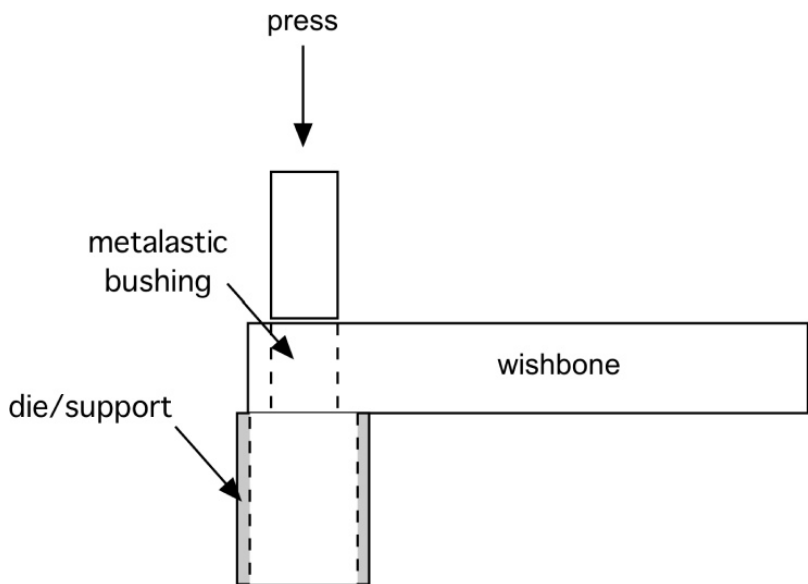
- J. Coulter, *Lotus Seven*, Amadeus Press (1995).

Restoring The Front Wishbones

The front wishbones for the Series 4 Lotus Seven are also used on the Lotus Europa and are bespoke Lotus items. The wishbones are actually formed in two halves (front and rear) being joined at the hub via a ball joint at the top and the trunnion at the bottom. Each of the wishbone halves is unique (i.e., the front and rear halves are handed and the lower and upper halves are different lengths). Each wishbone half is made from sheet steel folded into a U-shaped channel to which a steel tube is welded at one end. A metalastic bushing (metal-rubber-metal) is then press fitted into the tube for attachment to the chassis.

In general the metalastic bushes in the front wishbone halves corrode with time, in particular the rubber is susceptible to atmospheric degradation causing it to dry and crack, while oil and fluids cause the rubber to decay. However, the type 636 bushes are readily available and easily replaced. The metalastic bushes in the front wishbone halves were badly damaged by fire and needed replacing. These are removed by using a 10 ton hydraulic press with a 3/4" socket, while supporting the end of the wishbone ([\[link\]](#)).

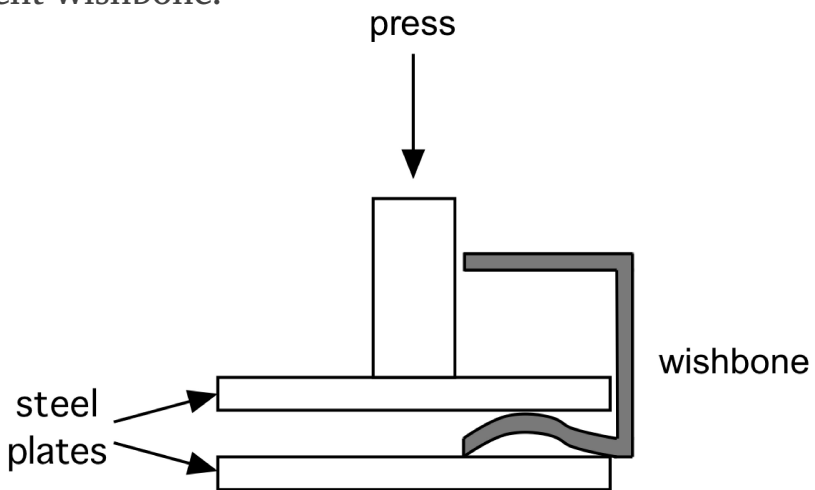
Schematic of a typical set-up for removal of the metalastic bushes from the front wishbone halves.



In addition to the bushes, all of the wishbones had been bent ([\[link\]](#)). The best method for straightening the wishbone's U-section without causing further damage to the metal is to use a hydraulic press. The bent sections of the wishbone were placed between two steel plates ([\[link\]](#)) and the plates squeezed in a hydraulic press to 20 tones. This method allows for the wishbone halves to be easily straightened as is shown in [\[link\]](#) and [\[link\]](#). A bent wishbone half before straightening with major bends arrowed.



Schematic of a typical set-up for straightening a bent wishbone.



A bent wishbone half after straightening one side with remaining bend arrowed.



A wishbone half after straightening both sides.



Once straight, the wishbone halves were media blasted to remove all rust and residual paint. While the wishbones were originally painted black, better

protection is obtained by powder coating. [\[link\]](#) shows one of the three different wishbone components after powder coating by Custom Coatings (Cypress, TX). It is important not to powder coat inside the cylinder into which the new metalastic bushing is to be fitted. Any overcoat must be carefully removed.

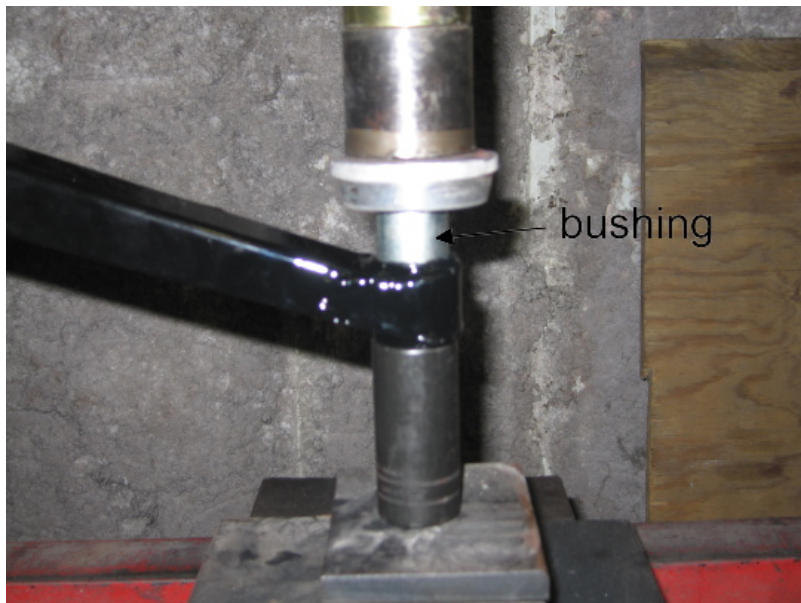
The wishbone components after media cleaning and powder coating. One of the lower wishbone halves (A), the rear upper wishbone (B) and the front upper wishbones (C), see [\[link\]](#).



The new bushes, purchased from Redline Components, Ltd. (Caterham, UK), are press fitted to the wishbone halves using a 10 ton hydraulic press while supporting the end of the wishbone with a socket ([\[link\]](#)). Once the bushes are in place for each of the wishbone components ([\[link\]](#) - [\[link\]](#)),

the completed wishbones are ready for instillation ([\[link\]](#)).

A typical set-up for fitting the metalastic bushes from the front wishbone halves.



One of the restored lower wishbone halves showing the metalastic bushing.



One of the restored upper front wishbone halves showing the metalastic bushing.



The restored left hand upper rear wishbone half showing the metalastic bushing.



The complete set of restored wishbones for the Lotus Seven S4.



Resources

- Redline Components, Ltd. Timber Hall, 19 Timber Lane, Caterham, Surrey, CR3 6LZ, UK. Tel: +44 (0)1883 346515.
www.redlinecomponents.co.uk.
- Lucas Racing and Restoration, 10030 Talley Lane, Houston, TX 77041, USA. Tel: +1 713 462 0068. www.lucasracinginc.com.
- Custom Coatings, 16219 Dundee, Cypress, TX 77429, USA. Tel: +1 281 813 0119.

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Restoring The Front Uprights, Hubs, and Disks

Schematic of a proton exchange membrane fuel cell (PEMFCs).

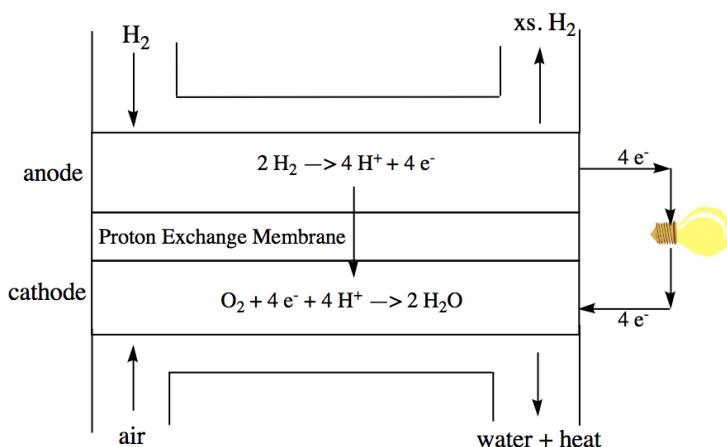
Introduction

Proton exchange membrane fuel cells (PEMFCs) are one promising alternative to traditional combustion engines. This method takes advantage of the exothermic hydrogen oxidation reaction in order to generate energy and water ([\[link\]](#)).

	Acidic electrolyte	Acidic redox potential at STP (V)	Basic electrolyte	Basic redox potential at STP (V)
Anode half-reaction	$2\text{H}_2 \longrightarrow 4\text{H}^+ + 4\text{e}^-$		$2\text{H}_2 + 4\text{OH}^- \longrightarrow 4\text{H}_2\text{O} + 4\text{e}^-$	
Cathode half-reaction	$\text{O}_2 + 4\text{e}^- + 4\text{H}^+ \longrightarrow 2\text{H}_2\text{O}$	1.23	$\text{O}_2 + 4\text{e}^- + 2\text{H}_2\text{O} \longrightarrow 4\text{OH}^-$	0.401

Summary of oxidation-reduction reactions in a PEMFC in acidic and basic electrolytes.

The basic PEMFC consists of an anode and a cathode separated by a proton exchange membrane ([\[link\]](#)). This membrane is a key component of the fuel cell because for the redox couple reactions to successfully occur, protons must be able to pass from the anode to the cathode. The membrane in a PEMFC is usually composed of Nafion, which is a polyfluorinated sulfonic acid, and exclusively allows protons to pass through. As a result, electrons and protons travel from the anode to the cathode through an external circuit and through the proton exchange membrane, respectively, to complete the circuit and form water.



PEMFCs present many advantages compared to traditional combustion engines. They are more

efficient and have a greater energy density than traditional fossil fuels. Additionally, the fuel cell itself is very simple with few or no moving parts, which makes it long-lasting, reliable, and very quiet. Most importantly, however, the operation of a PEMFC results in zero emissions as the only byproduct is water ([\[link\]](#)). However, the use of PEMFCs has been limited because of the slow reaction rate for the oxygen reduction half-reaction (ORR). Reaction rates, k° , for reduction-oxidation reactions such as these tend to be on the order of 10^{-10} – 10^{-9} where 10^{-10} is the fastest reaction rate and 10^{-9} is the slowest reaction rate. Compared to the hydrogen oxidation half-reaction (HOR), which has a reaction rate of $k^\circ = 1 \times 10^{-10}$ cm/s, the reaction rate for the ORR is $k^\circ \sim 1 \times 10^{-9}$ cm/s. Thus, the ORR is the kinetic rate-limiting half-reaction and its reaction rate must be increased for PEMFCs to be a viable alternative to combustion engines. Because cyclic voltammetry can be used to examine the kinetics of the ORR reaction, it is a critical technique in evaluating potential solutions to this problem.

Advantages	Disadvantages
More efficient than combustion engines	ORR half-reaction too slow for commercial use

Greater energy density than fossil fuels	Hydrogen fuel is not readily available
Long-lasting	Water circulation must be managed to keep the proton exchange membrane hydrated
Reliable	
Quiet	
No harmful emissions	

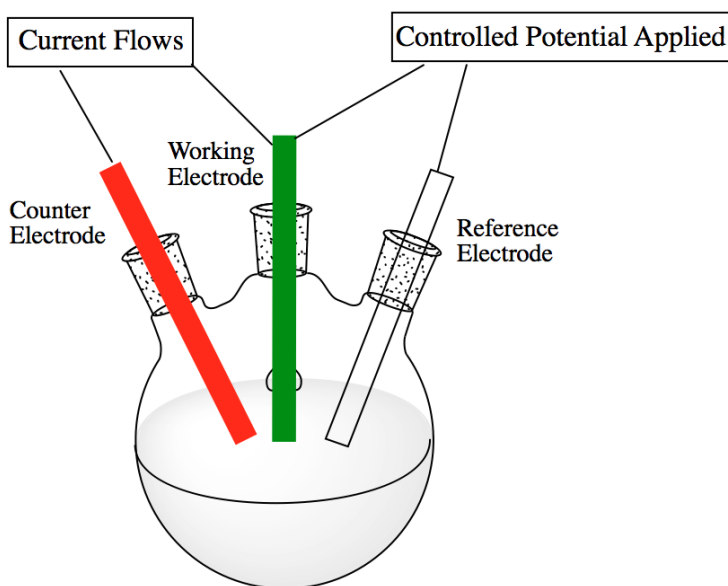
Summary of advantages and disadvantages of PEMFCs as an alternative to combustion engines. A simple three electrode cell. Triangular waveform demonstrating the cycling of potential with time. Example of an idealized cyclic voltammogram. Reprinted with permission from P. T. Kissinger and W. R. Heineman, *J. Chem. Educ.*, 1981, **60**, 702. Copyright 1983 American Chemical Society

Cyclic voltammetry

Overview

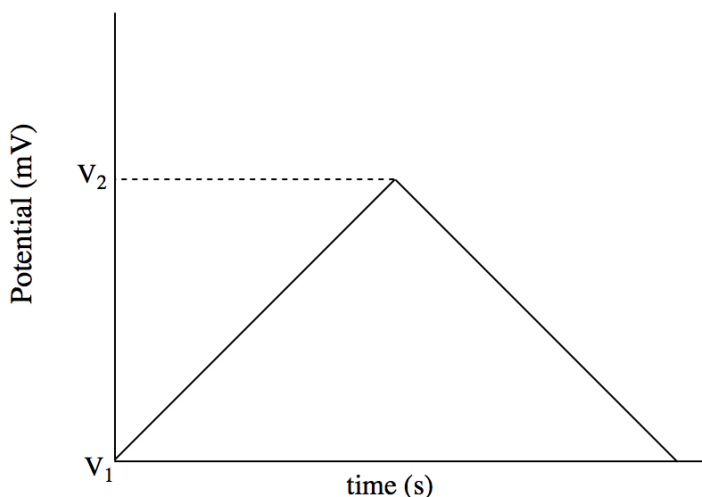
Cyclic voltammetry is a key electrochemical technique that, among its other uses, can be employed to examine the kinetics of oxidation-reduction reactions in electrochemical systems. Specifically, data collected with cyclic voltammetry can be used to determine the rate of reaction. In its simplest form, this technique requires a simple three

electrode cell and a potentiostat [\[link\]](#).



A potential applied to the working electrode is varied linearly with time and the response in the current is measured [\[link\]](#). Typically, the potential is cycled between two values once in the forward direction and once in the reverse direction. For example, in [\[link\]](#), the potential is cycled between 0.8 V and -0.2 V with the forward scan moving from positive to negative potential and the reverse scan moving from negative to positive potential. Various parameters can be adjusted including the scan rate, the number of scan cycles, and the direction of the potential scan i.e. whether the forward scan moves from positive to negative voltages or vice versa. For publication, data is typically collected at a scan rate

of 20 mV/s with at least 3 scan cycles.

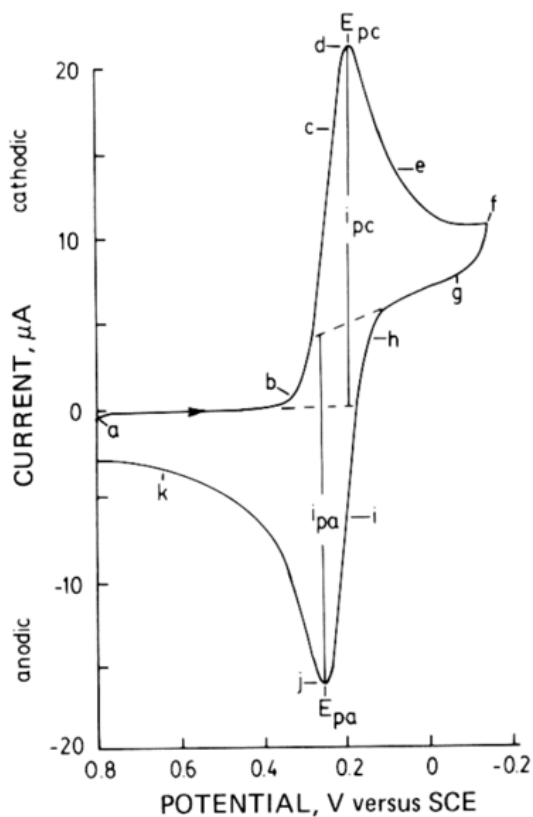


Reading a voltammogram

From a cyclic voltammetry experiment, a graph called a voltammogram will be obtained. Because both the oxidation and reduction half-reactions occur at the working electrode surface, steep changes in the current will be observed when either of these half-reactions occur. A typical voltammogram will feature two peaks where one peak corresponds to the oxidation half-reaction and the other to the reduction half-reaction. In an oxidation half-reaction in an electrochemical cell, electrons flow from the species in solution to the electrode resulting in an anodic current, i_a . Frequently, this oxidation peak appears when scanning from negative to positive potentials

([\[link\]](#)). In a reduction half-reaction in an electrochemical cell, electrons flow from the electrode to the species in solution, resulting in a cathodic current, i_c . This type of current is most often observed when scanning from positive to negative potentials ([\[link\]](#)). When the starting reactant is completely oxidized or completely reduced, peak anodic current, i_{pa} , and peak cathodic current, i_{pc} , respectively, are reached. Then, the current decays as the oxidized or reduced species leaves the electrode surface. The shape of these anodic and cathodic peaks can be modeled with the Nernst equation, [\[link\]](#), where n is the number of electrons transferred and E° , (formal reduction potential) = $(E_{pa} + E_{pc})/2$

$$E_{eq} = E^\circ + (0.059/n) \log [\text{reactant}]/[\text{product}]$$



Important values from the voltammogram

Several key pieces of information can be obtained through examination of the voltammogram including i_{pa} , i_{pc} , and the anodic and cathodic peak potentials. i_{pa} and i_{pc} both serve as important measures of catalytic activity: the larger the peak currents, the greater the activity of the catalyst.

Values for i_{pa} and i_{pc} can be obtained through one of two methods: physical examination of the graph or the Randles-Sevcik equation. To determine the peak potentials directly from the graph, a vertical tangent line from the peak current is intersected with an extrapolated baseline. In contrast, the Randles-Sevcik equation uses information about the electrode and the experimental parameters to calculate the peak current, [\[link\]](#), where A = electrode area; D = diffusion coefficient; C = concentration; ν = scan rate.

$$i_p = (2.69 \times 10^5) n^{3/2} A D^{1/2} C \nu^{1/2}$$

Anodic peak potential, E_{pa} , and cathodic peak potential, E_{pc} , can also be obtained from the voltammogram by determining the potential at which i_{pa} and i_{pc} respectively occur. These values are an indicator of the relative magnitude of the reaction rate. If the exchange of electrons between the oxidizing and reducing agents is fast, they form an electrochemically reversible couple. These redox couples fulfill the relationship: $\Delta E_p = E_{pa} - E_{pc} \equiv 0.059/n$. In contrast, a nonreversible couple will have a slow exchange of electrons and $\Delta E_p > 0.059/n$. However, it is important to note that ΔE_p is dependent on scan rate.

Example of an idealized Tafel plot. Reprinted with the permission of Dr. Rob C.M. Jakobs under the

Analysis of reaction kinetics

The Tafel and Butler-Volmer equations allow for the calculation of the reaction rate from the current-potential data generated by the voltammogram. In these analyses, the rate of the reaction can be expressed as two values: k° and i_o . k° , the standard rate constant, is a measure of how fast the system reaches equilibrium: the larger the value of k° , the faster the reaction. The exchange current density, (i_o) is the current flow at the surface of the electrode at equilibrium: the larger the value of i_o , the faster the reaction. While both i_o and k° can be used, i_o is more frequently used because it is directly related to the overpotential through the current-overpotential and Butler-Volmer equations. When the reaction is at equilibrium, k_o and i_o are related by [\[link\]](#), where $C_{o,eq}$ and $C_{R,eq}$ = equilibrium concentrations of the oxidized and reduced species respectively and a = symmetry factor.

$$i_o = nFk^\circ C_{o,eq}^{(1-a)} C_{R,eq}^a$$

Tafel equation

In its simplest form, the Tafel equation is expressed

as [\[link\]](#), where a and b can be a variety of constants. Any equation which has the form of [\[link\]](#) is considered a Tafel equation.

$$E - E^\circ = a + b \log(i)$$

For example, the relationship between current, potential, the concentration of reactants and products, and k° can be expressed as [\[link\]](#), where $C_O(0,t)$ and $C_R(0,t)$ = concentrations of the oxidized and reduced species respectively at a specific reaction time, F = Faraday constant, R = gas constant, and T = temperature.

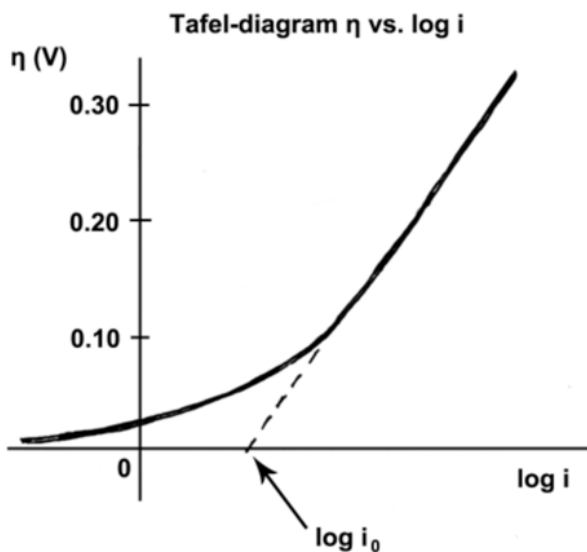
$$C_O(0,t) - C_R(0,t)e^{\{[nF/RT](E-E^\circ)\}} = [i/nF k^\circ] [e^{\{[1-\alpha]nF/RT\}}]$$

At very large overpotentials, this equation reduces to a Tafel equation, [\[link\]](#), where $a = -[RT/(1-a)nF]\ln(i_o)$ and $b = [RT/(1-a)nF]$.

$$E - E^\circ = [RT/(1-a)nF]\ln(i) - [RT/(1-a)nF]\ln(i_o)$$

The linear relationship between $E - E^\circ$ and $\log(i)$ can be exploited to determine i_o through the formation of a Tafel plot ([\[link\]](#)), $E - E^\circ$ versus $\log(i)$. The resulting anodic and cathodic branches of the graph

have slopes of $[(1-a)nF/2.3RT]$ and $[-anF/2.3RT]$, respectively. An extrapolation of these two branches results in a y-intercept = $\log(i_0)$. Thus, this plot directly relates potential and current data collected by cyclic voltammetry to i_0 .



Butler-Volmer equation

While the Butler-Volmer equation resembles the Tafel equation, and in some cases can even be reduced to the Tafel formulation, it uniquely provides a direct relationship between i_0 and H . Without simplification, the Butler-Volmer equation is known as the current-overpotential [\[link\]](#).

$$i/i_o = [C_O(0,t)/C_{o,eq}] e^{\{[anF/RT](E-E^*)\}} - [C_R(0,t)/C_{R,eq}] e^{\{(1-a)nF/RT](E-E^*)\}}$$

If the solution is well-stirred, the bulk and surface concentrations can be assumed to be equal and [\[link\]](#) can be reduced to the Butler-Volmer equation, [\[link\]](#).

$$I = i_o [e^{\{[anF/RT](E-E^*)\}} - e^{\{(1-a)nF/RT](E-E^*)\}}]$$

Anodic sweeps of cyclic voltammograms of Pt, Pt3Sc, and Pt3Y in 0.1 M HClO₄ at 20 mV/s. Reprinted by permission from Macmillan Publishers Ltd: [Nature] J. Greeley, I. E. L. Stephens, A. S. Bondarenko, T. P. Johansson, H. A. Hansen, T. F. Jaramillo, J. Rossmeisl, I. Chorkendorff, and J. K. Nørskov, *Nat. Chem.*, 2009, **1**, 552. Copyright 2009. Comparison of Fe-PANI-C and Pt/C catalysts in basic electrolyte. Reprinted by permission from Macmillan Publishers Ltd: [Nature] H. T. Chung, J. H. Won, and P. Zelenay, *Nat. Commun.*, 2013, **4**, 1922, Copyright 2013. Comparison of Co-PANI-C and Fe-PANI-C catalysts by cyclic voltammetry for PANI-Fe-C catalysts. Reproduced from G. Wu, C.M. Johnston, N.H. Mack, K. Artyushkova, M. Ferrandon, M. Nelson, J.S. Lezama-Pacheco, S.D. Conradson, K.L. More, D.J. Myers, and P. Zelenay, *J. Mater. Chem.*, 2011, **21**, 11392-11405 with the permission of The Royal Society of Chemistry. Synthetic scheme for Fe-PANI-C catalyst. Reprinted

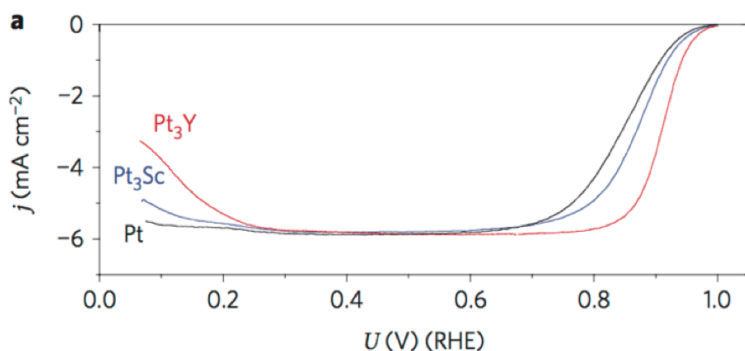
with the permission of the Royal Society of Chemistry under the CC BY-NC 3.0 License: N. Daems, X. Sheng, Y. Alvarez-Gallego, I. F. J. Vankelecom, and P. P. Pescarmona, *Green Chem.*, 2016, **18**, 1547. Copyright 2015. Comparison of synthetic techniques by cyclic voltammetry for PANI-Fe-C catalysts. Reproduced from G. Wu, C. M. Johnston, N. H. Mack, K. Artyushkova, M. Ferrandon, M. Nelson, J. S. Lezama-Pacheco, S. D. Conradson, K. L. More, D. J. Myers, and P. Zelenay, *J. Mater. Chem.*, 2011, **21**, 11392, with the permission of The Royal Society of Chemistry.

Cyclic voltammetry in ORR catalysis research

Platinum catalysis

While the issue of a slow ORR reaction rate has been addressed in many ways, it is most often overcome with the use of catalysts. Traditionally, platinum catalysts have demonstrated the best performance at 30 °C, the ORR i_0 on a Pt catalyst is 2.8×10^{-7} A/cm² compared to the limiting case of ORR where $i_0 = 1 \times 10^{-10}$ A/cm². Pt is particularly effective as a catalyst for the ORR in PEMFCs because its binding energy for both O and OH is the closest to ideal of all the bulk metals, its activity is the highest of all the bulk metals, its selectivity for O₂ adsorption is close to 100%, and its extreme

stability under a variety of acidic and basic conditions as well as high operating voltages [\[link\]](#).

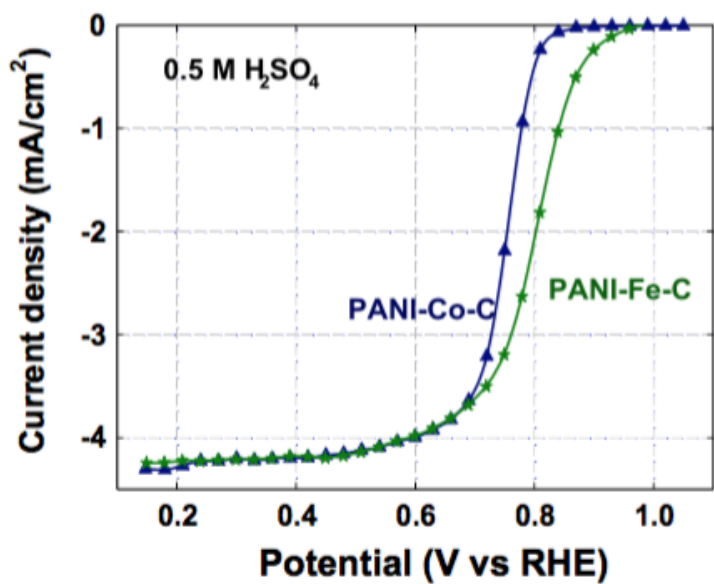
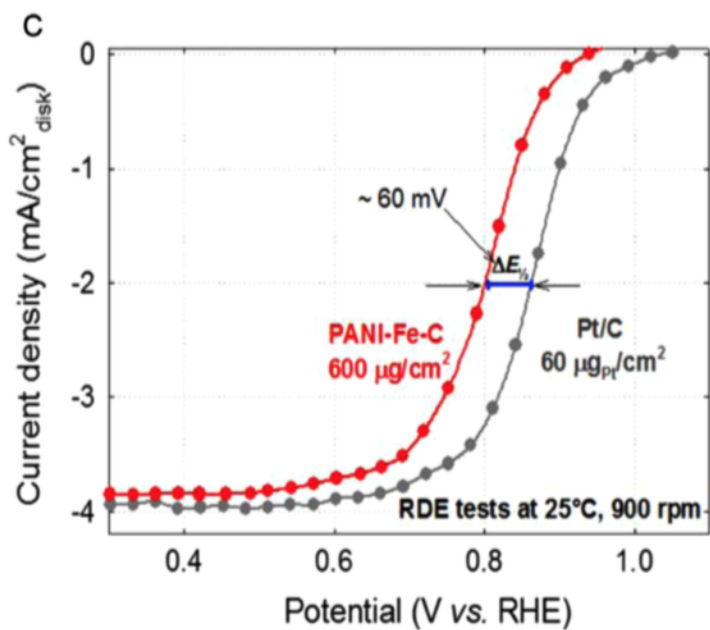


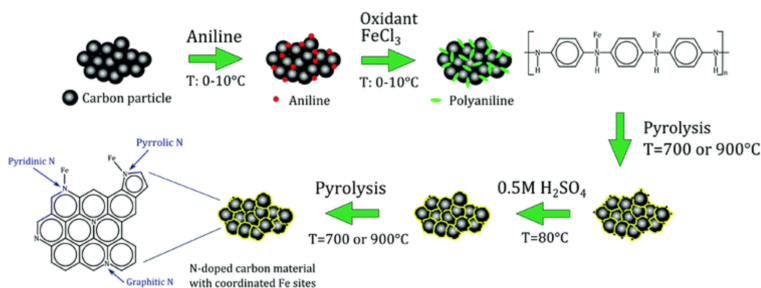
Metal-nitrogen-carbon composite catalysts

Nonprecious metal catalysts (NPMCs) show great potential to reduce the cost of the catalyst without sacrificing catalytic activity. The best NPMCs currently in development have comparable or even better ORR activity and stability than platinum-based catalysts in alkaline electrolytes; in acidic electrolytes, however, NPMCs perform significantly worse than platinum-based catalysts.

In particular, transition metal-nitrogen-carbon composite catalysts (M-N-C) are the most promising type of NPMC. The highest-performing members of this group catalyze the ORR at potentials within 60 mV of the highest-performing platinum catalysts ([\[link\]](#)). Additionally, these catalysts have excellent stability: after 700 hours at 0.4 V, they do not show any performance degradation. In a comparison of high-performing PANI-Co-C and PANI-Fe-C (PANI =

polyaniline), Zelenay and coworkers used cyclic voltammetry to compare the activity and performance of these two catalysts in H_2SO_4 . The Co-PANI-C catalyst was found to have no reduction-oxidation features on its voltammogram whereas Fe-PANI-C was found to have two redox peaks at ~ 0.64 ([\[link\]](#)). These Fe-PANI-C peaks have a full width at half maximum of ~ 100 mV, which is indicative of the reversible one-electron $\text{Fe}^{3+}/\text{Fe}^{2+}$ reduction-oxidation (theoretical FWHM = 96 mV). Zelenay and coworkers also determined the exchange current density using the Tafel analysis and found that Fe-PANI-C has a significantly greater i_0 ($i_0 = 4 \times 10^{-8}$ A/cm²) compared to Co-PANI-C ($i_0 = 5 \times 10^{-10}$ A/cm²). These differences not only demonstrate the higher ORR activity of Fe-PANI-C when compared to Co-PANI-C, but also suggest that the ORR-active sites and reaction mechanisms are different for these two catalysts. While the structure of Fe-PANI-C has been examined ([\[link\]](#)) the structure of Co-PANI-C is still being investigated.

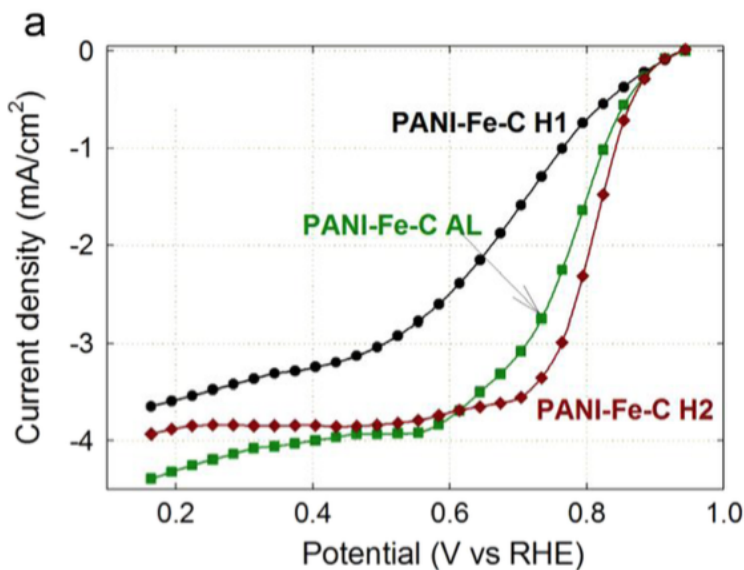




While the majority of the M-N-C catalysts show some ORR activity, the magnitude of this activity is highly dependent upon a variety of factors; cyclic voltammetry is critical in the examination of the relationships between each factor and catalytic activity. For example, the activity of M-N-Cs is highly dependent upon the synthetic procedure. In their in-depth examination of Fe-PANI-C catalysts, Zelenay and coworkers optimized the synthetic procedure for this catalyst by examining three synthetic steps: the first heating treatment, the acid-leaching step, and the second heating treatment. Their synthetic procedure involved the formation of a PANI-Fe-carbon black suspension that was vacuum-dried onto a carbon support. Then, the intact catalyst underwent a one-hour heating treatment followed by acid leaching and a three-hour heating treatment. The heating treatments were performed at 900°C, which was previously determined to be the optimal temperature to achieve maximum ORR activity ([\[link\]](#)).

To determine the effects of the synthetic steps on the intact catalyst, the Fe-PANI-C catalysts were

analyzed by cyclic voltammetry after the first heat treatment (HT1), after the acid-leaching (AL), and after the second heat treatment (HT2). Compared to HT1, both the AL and HT2 steps showed increases in the catalytic activity. Additionally, HT2 was found to increase the catalytic activity even more than AL ([link]). Based on this data, Zelenay and coworkers concluded HT1 likely either creates active sites in the catalytic surface while both the AL step removes impurities, which block the surface pores, to expose more active sites. However, this step is also known to oxidize some of the catalytic area. Thus, the additional increase in activity after HT2 is likely a result of “repairing” the catalytic surface oxidation.



Conclusion

With further advancements in catalytic research, PEMFCs will become a viable and advantageous technology for the replacement of combustion engines. The analysis of catalytic activity and reaction rate that cyclic voltammetry provides is critical in comparing novel catalysts to the current highest-performing catalyst: Pt.

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Assembly of the Front Suspension

Swedish chemist Arne W. K. Tiselius (1902–1971) who was the founding father of electrophoresis. Swedish chemist Stellan Hjerten (1928–present) who worked under Arne W. K. Tiselius that pioneered work in CE. James W. Jorgensen (1952–present).

Introduction

Capillary electrophoresis (CE) encompasses a family of electrokinetic separation techniques that uses an applied electric field to separate out analytes based on their charge and size. The basic principle is hinged upon that of electrophoresis, which is the motion of particles relative to a fluid (electrolyte) under the influence of an electric field. The founding father of electrophoresis, Arne W. K. Tiselius ([\[link\]](#)), first used electrophoresis to separate proteins, and he went on to win a Nobel Prize in Chemistry in 1948 for his work on both electrophoresis and adsorption analysis. However, it was Stellan Hjerten ([\[link\]](#)), who worked under Arne W. K. Tiselius, who pioneered work in CE in 1967, although CE was not well recognized until 1980 when James W. Jorgenson ([\[link\]](#)) and Kryn D. Lukacs published a series of papers describing this new technique.



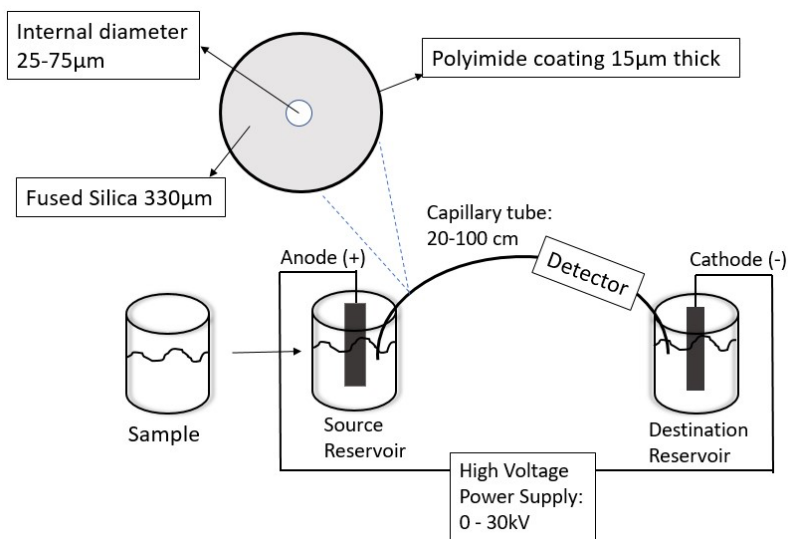




A schematic diagram of the components of a typical capillary electrophoresis setup and the capillary column.

Instrument overview

The main components of CE are shown in [\[link\]](#). The electric circuit of the CE is the heart of the instrument.



Injection methods

The samples that are studied in CE are mainly liquid samples. A typical capillary column has an inner diameter of 50 µm and a length of 25 cm. Because the column can only contain a minimal amount of running buffer, only small sample volumes can be tested (nL to µL). The samples are introduced mainly by two injection methods: hydrodynamic and electrokinetic injection. The two methods are displayed in [\[link\]](#). A disadvantage of electrokinetic injection is that the composition of the injected sample may not be the same as the composition of the original sample. This is because the injection method is dependent on the electrophoretic and electroosmotic mobility of the species in the sample. However, both injection methods depend on the

temperature and the viscosity of the solution. Hence, it is important to control both parameters when a reproducible volume of sample injections is desired. It is advisable to use internal standards instead of external standards when performing quantitative analysis on the samples as it is hard to control both the temperature and viscosity of the solution.

Injection method	Working Principle
Hydrodynamic injection	The sample vial is enclosed in a chamber with one end of capillary column immersed in it. Pressure is then applied to the chamber for a fixed period so that the sample can enter the capillary. After the sample, has been introduced, the capillary is withdrawn and then re-immersed into the source reservoir and separation takes place.
Electrokinetic injection	The sample is enclosed in a chamber with one end

of capillary column immersed in it with an electrode present. The electric field is applied, and the samples enter the capillary. After the sample, has been introduced, the capillary is withdrawn and then re-immersed into the source reservoir and separation takes place.

The working principle of the two injection methods used in CE.

Column

After the samples have been injected, the capillary column is used as the main medium to separate the components. The capillary column used in CE shares the same characteristics as the capillary column used in gas chromatography (GC); however, the most critical components of the CE column are:

- the inner diameter of the capillary,
- the total length of the capillary,
- the length of the column from the injector to the detector.

Solvent buffer

The solvent buffer carries the sample through the column. It is crucial to employ a good buffer as a successful CE experiment is hinged upon this. CE is based on the separation of charges in an electric field. Therefore, the buffer should either sustain the pre-existing charge on the analyte or enable the analyte to obtain a charge, and it is important to consider the pH of the buffer before using it.

Applied voltage (kV)

The applied voltage is important in the separation of the analytes as it drives the movement of the analyte. It is important that it is not too high as it may become a safety concern.

Detectors

Analytes that have been separated after the applying the voltage can be detected by many detection methods. The most common method is UV-visible absorbance. The detection takes place across the capillary with a small portion of the capillary acting as the detection cell. The on-tube detection cell is usually made optically transparent by scraping off the polyimide coating and coating it with another optically transparent material so that the capillary would not break easily. For species that do not have a chromophore, a chromophore can be added to the

buffer solution. When the analyte passes by, there would be a decrease in signal. This decreased signal will correspond to the amount of analyte present. Other common detection techniques employable in CE are fluorescence and mass spectrometry (MS).

An illustration of the electric double layer and movement of the species in solution. Adapted from D. Harvey, *Analytical Chemistry 2.0(e-textbook)*, 851.

An illustration of the order of elution of the charged species. Adapted from D. A. Skoog, D. M. West, F. J. Holler and S. R. Crouch, *Fundamentals of Analytical Chemistry*, Copyright Brooks Cole (2013).

A typical electropherogram demonstrating the order of elution of cations and anions. Adapted from J.

Sáiz, I. J. Koenka, T. Duc Mai, P. C. Hauser, C. García-Ruiz, *TrAC*, 2014, **62**. 162.

Theory

In CE, the sample is introduced into the capillary by the above-mentioned methods. A high voltage is then applied causing the ions of the sample to migrate towards the electrode in the destination reservoir, in this case, the cathode. Sample components migration and separation are determined by two factors, electrophoretic mobility and electroosmotic mobility.

Electrophoretic mobility

The electrophoretic mobility, μ_{ep} , is inherently dependent on the properties of the solute and the medium in which the solute is moving. Essentially, it is a constant value, that can be calculated as given by [\[link\]](#), where q is the solute's charge, η is the buffer viscosity and r is the solutes radius.

$$\mu_{ep} = q / 6 \pi \eta r$$

The electrophoretic velocity, v_{ep} , is dependent on the electrophoretic mobility and the applied electric field, E ([\[link\]](#)).

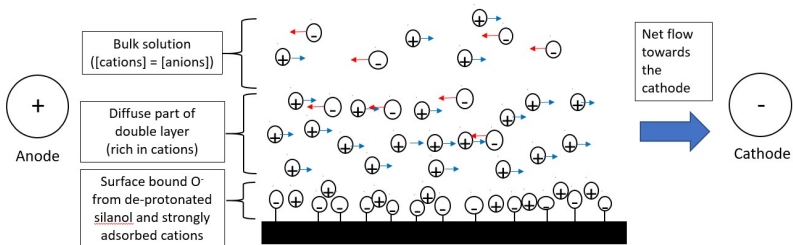
$$v_{ep} = \mu_{ep} E$$

Thus, when solutes have a larger charge to size ratio the electrophoretic mobility and velocity will increase. Cations and the anion would move in opposing directions corresponding to the sign of the electrophoretic mobility with is a result of their charge. Thus, neutral species that have no charge do not have an electrophoretic mobility.

Electroosmotic mobility

The second factor that controls the migration of the solute is the electroosmotic flow. With zero charge, it is expected that the neutral species should remain stationary. However, under normal conditions, the buffer solution moves towards the cathode as well. The cause of the electroosmotic flow is the electric double layer that develops at the silica solution interface.

At pH more than 3, the abundant silanol (-OH) groups present on the inner surface of the silica capillary, de-protonate to form negatively charged silanate ions (-SiO⁻). The cations present in the buffer solution will be attracted to the silanate ions and some of them will bind strongly to it forming a fixed layer. The formation of the fixed layer only partially neutralizes the negative charge on the capillary walls. Hence, more cations than anions will be present in the layer adjacent to the fixed layer, forming the diffuse layer. The combination of the fixed layer and diffuse layer is known as the double layer as shown in [\[link\]](#). The cations present in the diffuse layer will migrate towards the cathode, as these cations are solvated the solution will also flow with it, producing the electroosmotic flow. The anions present in the diffuse layer are solvated and will move towards the anode. However, as there are more cations than anions the cations will push the anions together with it in the direction of the cathode. Hence, the electroosmotic flow moves in the direction of the cathode.



The electroosmotic mobility, μ_{eof} , is described by [\[link\]](#), where ξ is the zeta potential, ϵ is the buffer dielectric constant and η is the buffer viscosity. The

electroosmotic velocity, v_{eof} , is the rate at which the buffer moves through the capillary is given by [\[link\]](#).

$$\mu_{eof} = \frac{\xi \epsilon}{4 \pi \eta}$$

$$v_{eof} = \mu_{eof} E$$

Zeta potential

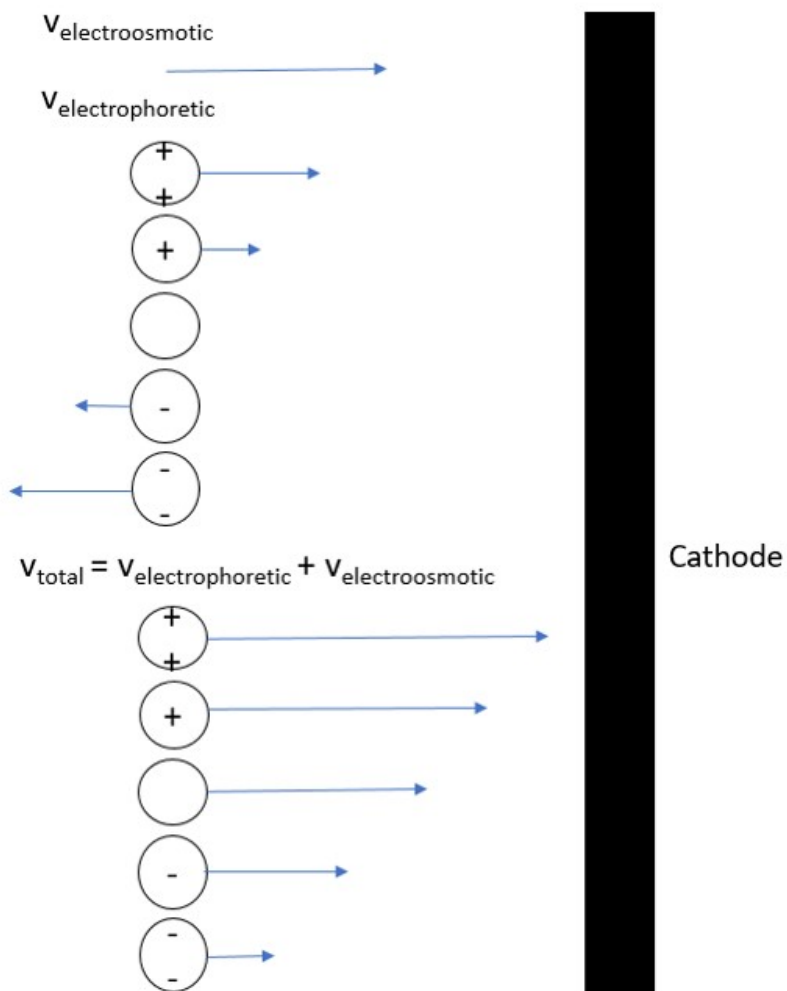
The zeta potential, ξ , also known as the electrokinetic potential is the electric potential at the interface of the double layer. Hence, in our case, it is the potential of the diffuse layer that is at a finite distance from the capillary wall. Zeta potential is mainly affected and directly proportional to two factors:

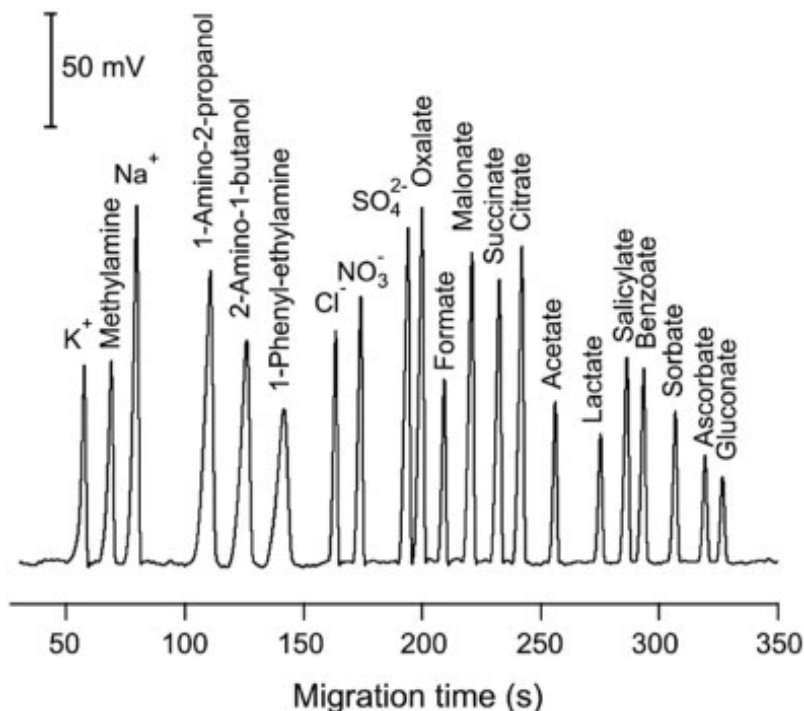
1. The thickness of the double layer. A higher concentration of cations possibly due to an increase in the buffer's ionic strength would lead to a decrease in the thickness of the double layer. As the thickness of the double layer decreases, the zeta potential would decrease that results in the decrease of the electroosmotic flow.
2. The charge on the capillary walls. A greater density of the silanate ions corresponds to a larger zeta potential. The formation of silanate ions is pH dependent. Hence, at pH less than 2 there is a decrease in the zeta potential and the electroosmotic flow as the silanol exists in its protonated form. However, as the pH increases,

there are more silanate ions formed causing an increase in zeta potential and hence, the electroosmotic flow.

Order of elution

Electroosmotic flow of the buffer is generally greater than the electrophoretic flow of the analytes. Hence, even the anions would move to the cathode as illustrated in [\[link\]](#). Small, highly charged cations would be the first to elute before larger cations with lower charge. This is followed by the neutral species which elutes as one band in the middle. The larger anions with low charge elute next and lastly, the highly charged small anion would have the longest elution time. This is clearly portrayed in the electropherogram in [\[link\]](#).





Optimizing the CE experiment

There are several components that can be varied to optimize the electropherogram obtained from CE. Hence, for any given setup certain parameters should be known:

- the total length of the capillary (L),
- the length the solutes travel from the start to the detector (l),
- the applied voltage (V).

Reduction in migration time, t_{mn}

To shorten the analysis time, a higher voltage can be used or a shorter capillary tube can be used. However, it is important to note that the voltage cannot be arbitrarily high as it will lead to joule heating. Another possibility is to increase μ_{eof} by increasing pH or decreasing the ionic strength of the buffer, [\[link\]](#).

$$t_{mn} = lL (\mu_{ep} + \mu_{eof})V$$

Efficiency

In chromatography, the efficiency is given by the number of theoretical plates, N . In CE, there exist a similar parameter, [\[link\]](#), where D is the solute's diffusion coefficient. Efficiency increases with an increase in voltage applied as the solute spends less time in the capillary there will be less time for the solute to diffuse. Generally, for CE, N will be very large.

$$N = \frac{l^2}{2Dt_{mn}} = \frac{\mu_{tot} V l^2}{2DL}$$

Resolution between two peaks

The resolution between two peaks, R , is defined by [\[link\]](#), where Δv is the difference in velocity of two solutes and $\tilde{v}$ is the average velocity of two solutes.

$$R = \frac{N}{4} \times \frac{\Delta v}{\tilde{v}}$$

Substituting the equation by N gives [\[link\]](#).

$$R = 0.177 \left(\mu_{ep,1} - \mu_{ep,2} \right) V D \left(\mu_{av} + \mu_{eof} \right)$$

Therefore, increasing the applied voltage, V , will increase the resolution. However, it is not very effective as a 4-fold increase in applied voltage would only give a 2-fold increase in resolution. In addition, increase in N , the number of theoretical plates would result in better resolution.

Selectivity

In chromatography, selectivity, α , is defined as the ratio of the two retention factors of the solute. This is the same for CE, [\[link\]](#), where t_2 and t_1 are the retention times for the two solutes such that, α is more than 1.

$$\alpha = \frac{t_2}{t_1}$$

Selectivity can be improved by adjusting the pH of the buffer solution. The purpose is to change the charge of the species being eluted.

Comparison between CE and HPLC

CE unlike High-performance liquid chromatography (HPLC) accommodates many samples and tends to have a better resolution and efficiency. A comparison between the two methods is given in Table [\[link\]](#).

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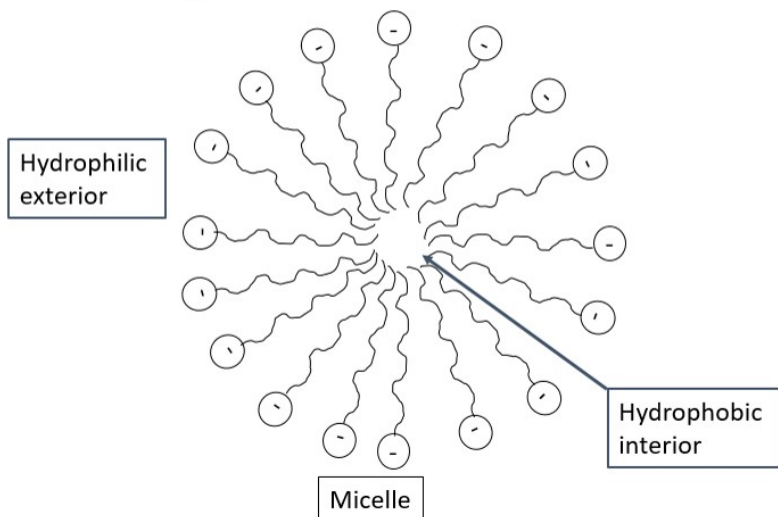
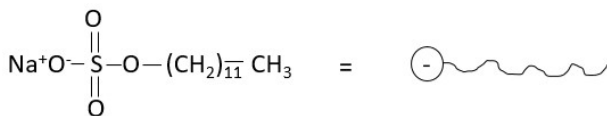
CE	HPLC
Wider selection of analyte to be analyzed	Limited by the solubility of the sample
Higher efficiency, no stationary mass transfer term as there is no stationary phase	Efficiency is lowered due to the stationary mass transfer term (equilibration between the stationary and mobile phase)
Electroosmotic flow profile in the capillary is flat as a result no band broadening. Better peak resolution and sharper peaks	Rounded laminar flow profile that is common in pressure driven systems such as HPLC. Resulting in broader peaks and lower resolution
Can be coupled to most detectors depending on application	Some detectors require the solvent to be changed and prior modification of the sample before analysis
Greater peak capacity as it uses a very large number of theoretical plates, N	The peak capacity is lowered as N is not as large
High voltages are used when carrying out the experiment	No need for high voltage

Advantages and disadvantages of CE versus HPLC. The structure of sodium dodecyl sulfate and its representation. An illustration of a cross section of a formed micelle. Adapted from D. Harvey, *Analytical*

Micellar electrokinetic chromatography

CE allows the separation of charged particles, and it is mainly compared to ion chromatography.

However, no separation takes place for neutral species in CE. Thus, a modified CE technique named micellar electrokinetic chromatography (MEKC) can be used to separate neutrals based on its size and its affinity to the micelle. In MEKC, surfactant species is added to the buffer solution at a concentration at which micelles will form. An example of a surfactant is sodium dodecyl sulfate (SDS) as seen in [\[link\]](#). The formation of the hydrophobic interior would allow the encapsulation of the neutral species. Whilst, the negatively charge hydrophilic exterior allows the molecule to be treated as an anion. Thus, it would move towards the cathode with a velocity less than the electroosmotic flow.



Neutral molecules are in dynamic equilibrium between the bulk solution and interior of the micelle. In the absence of the micelle the neutral species would reach the detector at t_0 but in the presence of the micelle, it reaches the detector at t_{mc} , where t_{mc} is greater than t_0 . The longer the neutral molecule remains in the micelle, the longer it's migration time. Thus small, non-polar neutral species that favor interaction with the interior of the micelle would take a longer time to reach the detector than a large, polar species. Anionic, cationic and zwitter ionic surfactants can be added to change the partition coefficient of the neutral species. Cationic surfactants would result in positive micelles that would move in the direction of electroosmotic flow. This enables it to move faster

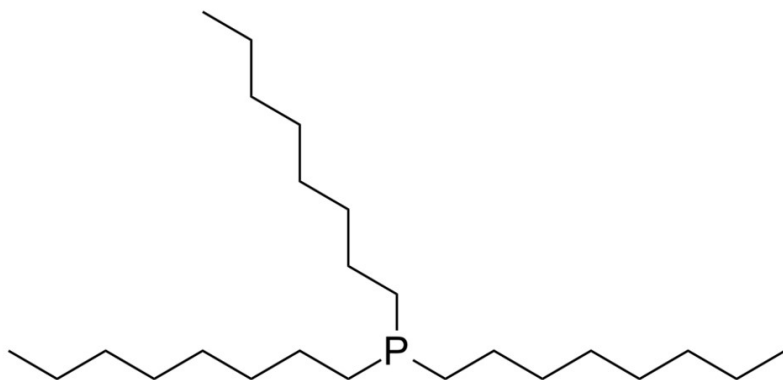
towards the cathode. However, due to the fast migration, it is possible that insufficient time is given for the neutral species to interact with the micelle resulting in poor separation. Thus, all factors must be considered before choosing the right surfactant to be used. The mechanism of separation between MEKC and liquid chromatography is the same. Both are dependent on the partition coefficient of the species between the mobile phase and stationary phase. The main difference lies in the pseudo stationary phase in MEKC, the micelles. The micelle which can be considered the stationary phase in MEKC moves at a slower rate than the mobile ions.

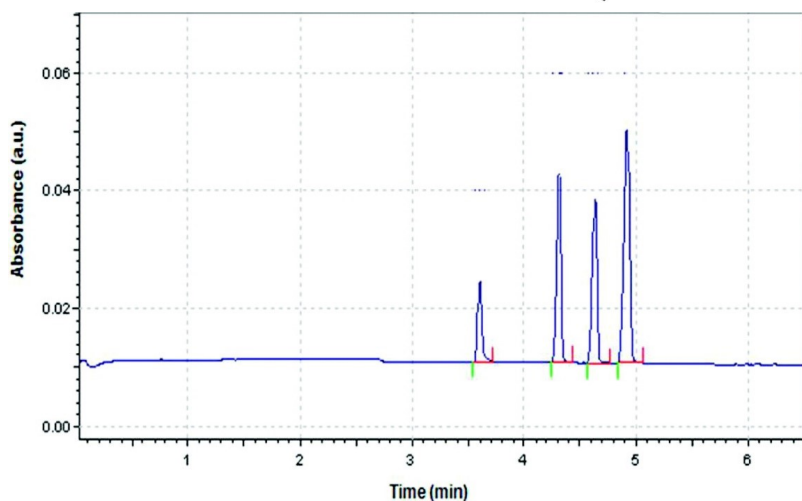
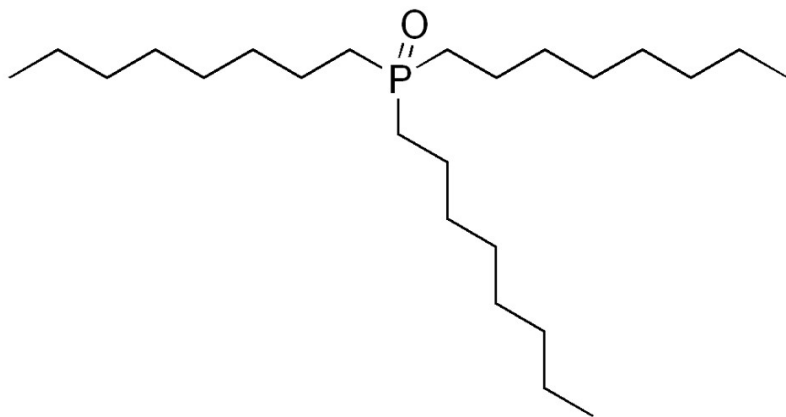
The structure of trioctylphosphine (TOP). The structure of trioctylphosphine oxide (TOPO). Electropherogram for a mixture of four different CdSe-TOPO/TOP-SDS complexes. Reproduced from C. Carrillo-Carrión, Y. Moliner-Martínez, B. M. Simonet, and M. Valcárcel, *Anal. Chem.*, 2011, **83**, 2807.

Case study: the use of CE in separation of quantum dots (QD)

Quantum dots are semiconductor nanocrystals that lie in the size range of 1-10 nm, and they have different electrophoretic mobility due to their varying sizes and surface charge. CE can be used to separate and characterize such species, and a method to characterize and separate CdSe QD in the

aqueous medium has been developed. The QDs were synthesized with an outer layer of trioctylphosphine (TOP, [\[link\]](#)) and trioctylphosphine oxide (TOPO, [\[link\]](#)), making the surface of the QD hydrophobic. The background electrolyte solution used was SDS, in order to make the QDs soluble in water and form a QD-TOPO/TOP-SDS complex. Different sizes of CdSe were used and the separation was with respect to the charge-to-mass ratio of the complexes. It was concluded from the study that the larger the CdSe core (i.e., the larger the charge-to-mass ratio) eluted out last. The electropherogram from the study is shown in [\[link\]](#), from which it is visible that good separation had taken place by using CE. Laser-induced fluorescence detection was used, the buffer system was SDS, and the pH of the system set up was fixed at 6.5. The pH is highly important in this case as the stability of the system and the separation is dependent on it.





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Installation of Front Stub Axles, Wheel Bearings, and Hubs

The wheel bearings and stub axles for the Series 4 Lotus Seven were sourced from Triumph, in particular the Herald. While the wheel bearings are also common to the Triumph Spitfire, the axles are not the same. The Spitfire axles, which are also used in the Lotus Seven S3, are too long and if fitted in the upright insufficient thread extends out of the rear of the upright. The hubs are chosen to have a Ford bolt pattern (4 x 4 1/4") to match the Ford sourced rear axle.

View of the stub axle inserted into the left upright.
View of the stub axle from the inner side. View of the stub axle after tightening the 1/2" nyloc nut.

The front stub axle

The stub axles were obtained from Redline Components, Ltd. Before sliding into the upright, a liberal amount of copper anti-seize (Permatex®) is used. The axle fits in from the outside ([\[link\]](#)). From the inner side a washer is placed over the stub ([\[link\]](#)) followed by a 1/2" thread nyloc nut ([\[link\]](#)). In order to torque the nyloc nut it is necessary to temporarily put a nut on the hub side.







An example of a typical bearing race driver set. View of the outer bearing race positioned before fitting into the hub. Note the support of the disk/hub on two pieces of wood. The bearing race driver in position. The outer bearing race in its correct location. The bearing race driver in position in the inner bearing race. The inner bearing race in its

correct location. The greased inner bearing in the inner bearing race.

Bearings

New bearings were sourced from Moss Motors. It is best to use a bearing race driver set ([\[link\]](#)) to install the bearing races. However, if not available using the old bearing race is acceptable, but care should be taken in ensuring the race is fitted correctly.



First it is good practice to wipe the location where

the bearing race will fit, to ensure no dirt will stop the race being inserted correctly. The outer bearing race is placed into location on the outer side of the hub ([\[link\]](#)). Then using the race driver set ([\[link\]](#)) the race is tapped in place with a hammer ([\[link\]](#)). It is best to support the disks on two pieces of wood to ensure that the inner side of the hub/disk combination is not damaged (see [\[link\]](#)).





The inner bearing race is fitted in the same manner ([\[link\]](#) and [\[link\]](#)); however, it is even more important to support the outer side of the hub on two pieces of wood so that the studs do not get

damaged.

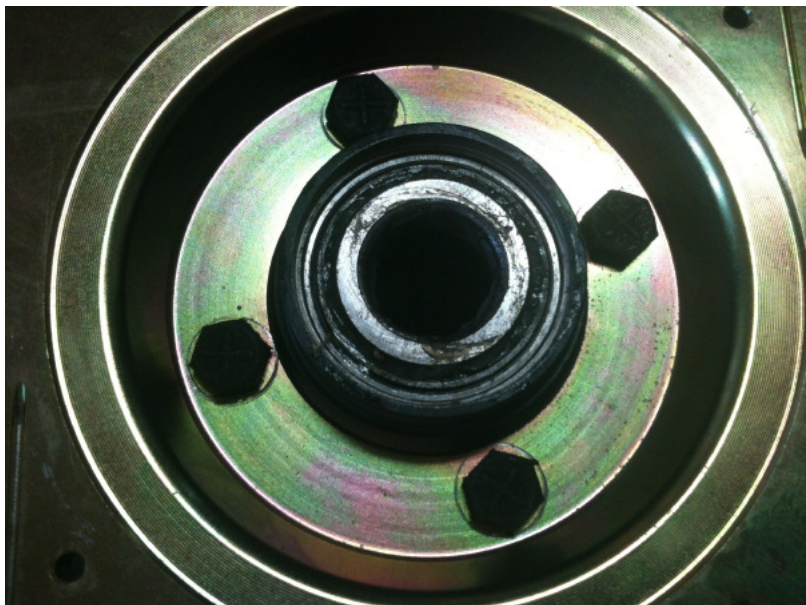


The packing of the bearings is the messiest part of the overall process. It is important to wear suitable gloves while doing this. Disposable nitrile butyl

rubber surgical gloves are the best; however, when these are not available the typical home washing up (dish washing) gloves will work, e.g., Marigold®. The easiest way to pack the bearing is to follow these steps:

Place a large glob of suitable bearing grease (e.g., MasterPro® Chemicals - High-Temp Wheel Bearing Grease) in the palm of your left hand (assuming you are right handed). Hold either side of the bearing faces (so that it cannot come apart) between the thumb and first finger of your right hand. Press the edge of one face of the bearing into the grease. Each time this is done a small amount of grease will work its way up into the bearing. Once grease starts to ooze out of the other face of the bearing rotate the bearing and repeat. Once the bearing is packed with grease smear the excess around the outside.

With the hub/disk combination stud side down the grease packed inner bearing is gently pushed into position ([\[link\]](#)) ready to mount the hub/disk onto the stub axle.



The bearing grease seal in place over the stub axle. The hub/disk assembly located on the stub axle with the outer bearing located into its race. The D-shaped washer (A), crenellated nut (B), and cotter (split) pin (C). The installed hub assembly with the retaining D-washer. The installed hub assembly with the crenellated nut and cotter (split) pin. The installed hub assembly with the cotter (split) pin bent and cut. The final installed hub assembly with the grease cap in place.

Install hub and disk unit

Before the hub/disk unit can be installed, the bearing grease seal is placed over the stub axle ([\[link\]](#)). This unit consists of a circular metal with a felt washer on one side. The felt fits up against the

hub, and it locates into a grove on the face of the hub.

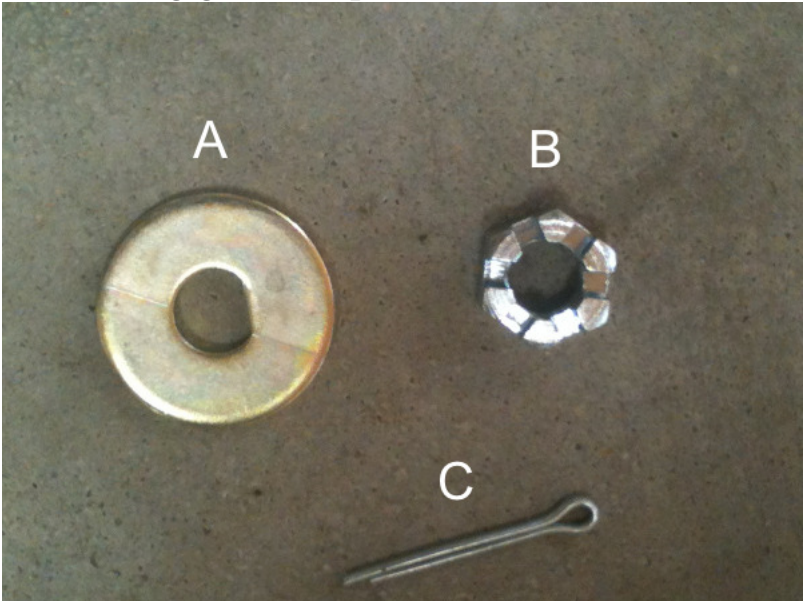


While holding the inner bearing into its race, the hub/disk assembly is carefully slid over the stub axle until the inner bearing slides all the way to the dust washer. Care should be taken to ensure that the bearing is fitted on straight. With the inner bearing/hub/disk in place, the outer bearing is slid over the stub axle and while supporting the hub is pushed along the axle until it fits into its race ([\[link\]](#)).



The entire hub assembly and the bearings are held in place on the stub axle by a washer that has a D-shaped hole such that it does not rotate on the axle ([\[link\]](#)A) and a crenellated nut ([\[link\]](#)B), which in turn is held in with a cotter (split) pin ([\[link\]](#)C). Once the hub is in place the D-washer is located ([\[link\]](#)) and the crenellated nut is screwed on. The crenellated nut is designed such that once suitably tightened the cotter pin will slide through the crenellations and through the hole in the axle (see [\[link\]](#)). In general, the nut is tightened until the hub will only turn with difficulty and then backed off to the last location at which the crenellations and hole align. The cotter pin is then pushed through ([\[link\]](#)) and then split by bending the ends over ([\[link\]](#)). Depending on the length of the pin it may be necessary to cut one arm on the pin so that the

outer bearing grease cap can be installed ([\[link\]](#)).









Resources

- Redline Components, Ltd. Timber Hall, 19 Timber Lane, Caterham, Surrey, CR3 6LZ, UK. Tel: +44 (0)1883 346515. www.redlinecomponents.co.uk.
- Moss Motors, Ltd. 440 Rutherford Street, Goleta, CA 93117, USA. Tel: +1 800 667 7872 or +1 805 681 3400. www.mossmotors.com.

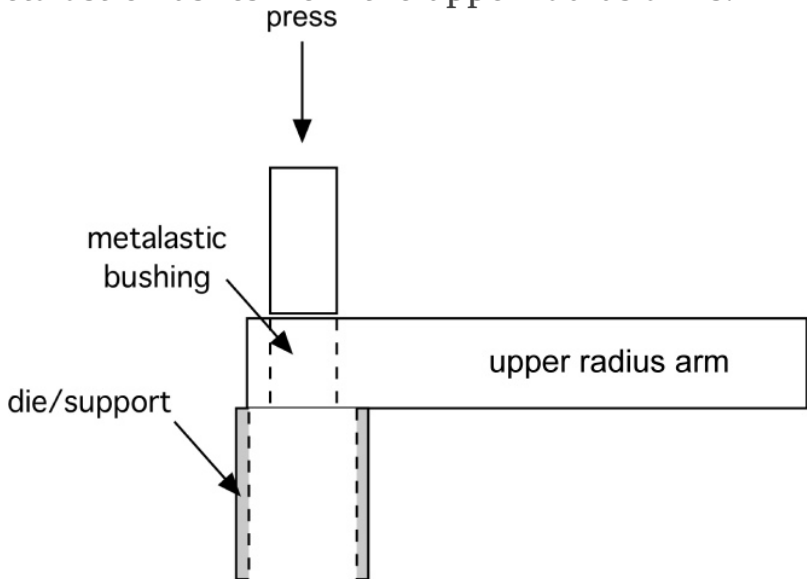
Restoring The Rear Radius Arms and Axle Locating Link

The rear radius arms and the associated axle locating arm for the Series 4 Lotus Seven are bespoke items. The upper radius arms are tubular and bent at the point they meet the chassis mounts. The single lower radius arm is straight and located on the right hand side, while the left hand lower radius arm is incorporated into the axle locating arm. A metalastic bushing (metal-rubber-metal) is then press fitted into the upper radius arms for attachment into the rear of the chassis, while rubber bushings are used for the axle ends of the radius arms and axle locating link, as well as the central chassis mounting. Large rubber bushings are used for attachment of the front of the lower radius arm and axle locating link to the chassis ([\[link\]](#)). The bushes used for the outer chassis mounts to the lower radius arm and the axle locating link on the Seven S4.



In general the metalastic bushes in the upper radius arms corrode with time, in particular the rubber is susceptible to atmospheric degradation causing it to dry and crack, while oil and fluids cause the rubber to decay. However, the type 636 bushes are readily available and easily replaced. The metalastic bushes in the upper radius arms were dried but not appreciably affected by the fire; however, they needed replacing. These are removed by using a 10 ton hydraulic press with a 3/4" socket, while supporting the end of the wishbone ([\[link\]](#)). One of the upper radius arms with the old bushing, and after its removal, is shown in [\[link\]](#) and [\[link\]](#), respectively. The type bushes are readily removed from the axle ends of the upper radius arms, the lower radius arm, and the axle locating link. Schematic of a typical set-up for removal of the

metalastic bushes from the upper radius arms.



The chassis end of one of the upper radius arms showing the original 636 bushing.



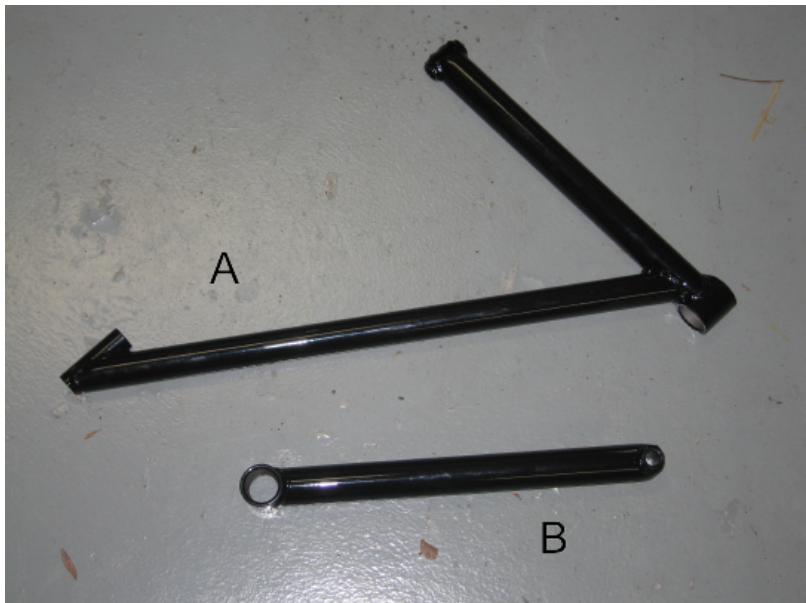
The chassis end of one of the upper radius arms after removal of the original 636 bushing (shown at

the side).



Once the bushings were removed the radius arms and axle control link were media blasted to remove all rust and residual paint. While the rear suspension components were originally painted black, better protection is obtained by powder coating. [\[link\]](#) shows the lower radius arm and the axle locating link after powder coating by Custom Coatings (Cypress, TX). It is important not to powder coat inside the cylinder into which the new metalastic bushing is to be fitted. Any overcoat must be carefully removed.

The axle locating link (A) and lower radius arm (B) after media cleaning and powder coating.



The new bushes, purchased from Redline Components, Ltd. (Caterham, UK), are press fitted to the upper radius arms using a hydraulic press ([\[link\]](#)), and are now ready for instillation ([\[link\]](#)). The remaining bushings are fitted during instillation in the chassis.

A typical set-up for fitting the metalastic bushes into the rear upper radius link.



The restored upper radius links for the Lotus Seven S4.



Resources

- Redline Components, Ltd. Timber Hall, 19 Timber Lane, Caterham, Surrey, CR3 6LZ, UK. Tel: +44 (0)1883 346515. www.redlinecomponents.co.uk.
- Lucas Racing and Restoration, 10030 Talley Lane, Houston, TX 77041, USA Tel: +1 713 462 0068. www.lucasracinginc.com.
- Custom Coatings, 16219 Dundee, Cypress, TX 77429, USA. Tel: +1 281 813 0119.

Restoring The Rear Axle

The rear live axle for the Series 4 Lotus Seven was sourced from the Ford Escort.

The rear axle after removal from the car. The drain plug is on the lower right hand side of the differential housing. Close-up of the right hand drum showing the retaining screw (arrowed). Loosening of the drum. Removal of the drum. Inside of the drum showing the brake surface and the residual brake shoe dust. Inside of the rear hub showing the brake shoes and the slave cylinder. Inside of the rear hub showing the retaining clips for the brake shoes (A) and access holes to the retaining bolts for the shafts (B). The brake shoe locating pin after removal of the retaining washers and spring. The shorter brake shoe tension spring. The longer brake shoe tension spring shown behind the brake slave cylinder. The two brake shoes with the two tension springs after removal from the drum. The hand brake connection to the rear brake slave cylinders. The two retaining clips that hold the slave cylinder into the drum. Demonstrating the attachment of a puller to the hub to facilitate removal of the half-shafts. Image of a half-shaft removed from the axle showing the splined end (Copyright: Ivan Samila).

Disassembly

As removed from the car ([\[link\]](#)), the axle rotates freely, and the hand brake/rear brakes appear to activate easily. However, given the total restoration of the car, it is a chance to rebuild the axle in particular the replacement of the bearings.



The first task is to drain the majority of the oil from

the axle. The drain plug is positioned at the rear of the differential housing ([\[link\]](#)). Once the majority of the oil is drained the hubs and shafts can be removed. Placing the axle on a suitable bench facilitates work.



Removal of the lug nuts and the retaining screw ([\[link\]](#)) allows for the drum to be removed. In the present case dirt and rust meant that the drum had to be loosened using a large screwdriver ([\[link\]](#)); however, once loose, the drum is removed by sliding off the studs ([\[link\]](#)). The insides of the drum show no significant wear, but a large quantity of brake shoe dust is present, that will need to be cleaned ([\[link\]](#)).



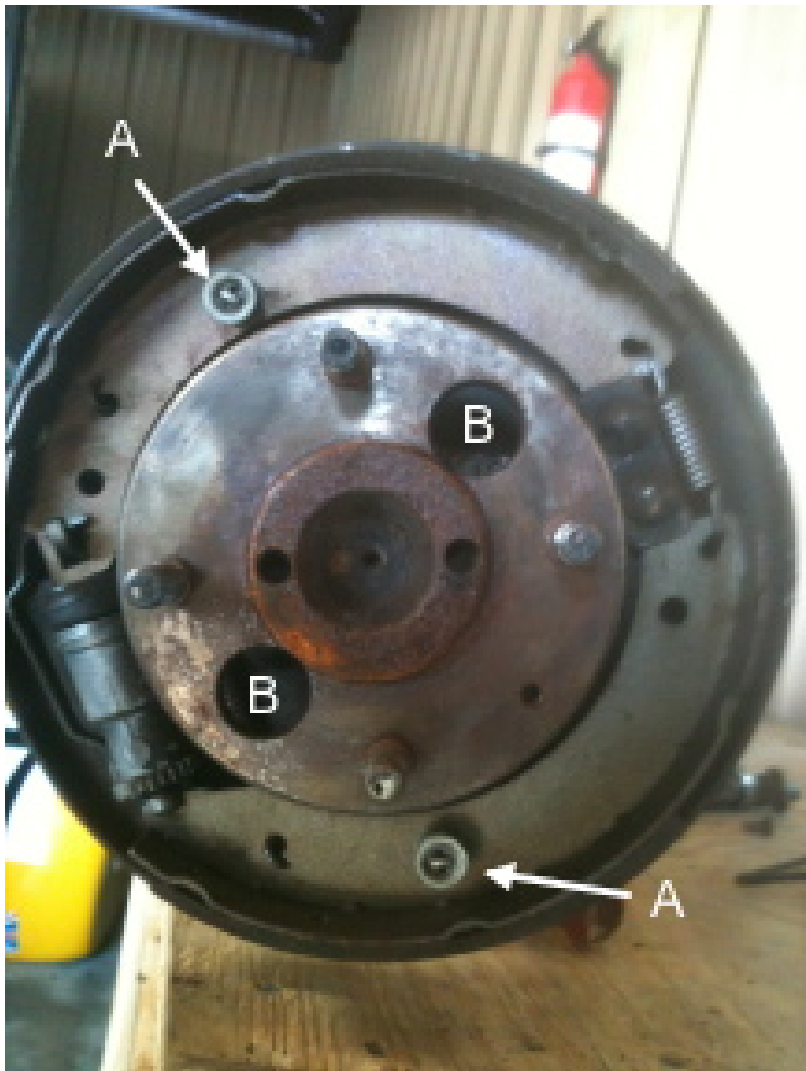






With the drum removed the state of the brake shoes can be determined, as well as if there are any leaks of the brake slave cylinder ([\[link\]](#) and [\[link\]](#)).





To remove the brake shoes, the pin of the retainer is twisted until it lines up with the slot in the washers ([\[link\]](#) and [\[link\]](#)). The outer retaining washer, along with the tensioning spring, and an inner washer are then removed ([\[link\]](#)). The brake shoes can then be pulled out of the hub. It is easier to remove both brake shoes along with the tensioning

springs ([\[link\]](#) and [\[link\]](#)), rather than trying to disengage the springs first. The brake shoes along with the tension springs are shown in [\[link\]](#).









The rear brakes are activated both pneumatically (foot brake) and mechanically (hand brake). To remove the brake slave cylinder, first disconnect the pneumatic line, and then the self-tensioner ratchet ([\[link\]](#)). With the hand brake lever disconnected ([\[link\]](#)) the rubber boot/dust cover is removed from the inboard side of the drum. With the rubber cover

removed the two retaining clips ([\[link\]](#)) can be slid out of the way and the slave cylinder and its associated lever can be removed.





By rotating the hub, the four retaining bolts for the backing plate can be removed two at a time, by lining up the bolt heads with the holes in the hubs ([\[link\]](#)). With the bolts removed, the half shaft may be pulled free. Because the bearings are press fit items this may require the use of a puller ([\[link\]](#)). In the present case, the bearings were rusted in place and significant force was needed. The half shafts are 22 spline ([\[link\]](#)).



Cleaning, painting, and rebuilding

Replacement hub and nose bearings were obtained from Redline Components (Caterham, UK), while the axle casing was rebuilt by Lucas Racing and Restoration (Houston, TX). The old hub bearings were removed from the axle shafts, and replaced with the new bearings.

Resources

- Redline Components, Ltd. Timber Hall, 19 Timber Lane, Caterham, Surrey, CR3 6LZ, UK. Tel: +44 (0)1883 346515. www.redlinecomponents.co.uk.
- Lucas Racing and Restoration, 10030 Talley Lane, Houston, Texas 77041, USA Tel: +1 713 462 006. www.lucasracinginc.com.

Installation of Rear Axle and Suspension

For the Series 4 Lotus Seven the ends of the Ford Escort live axle were located by leading (lower) and trailing (upper) radius arms of the Watts linkage type, while the location of axle was achieved with an axle-locating link attached to the left hand side lower radius arm. The lower radius arms were mounted on big rubber bushes to compensate for the conflicted geometry as a result of bumps that is inherent on this geometry. TABLE lists a summary of the nut and bolts used in the rear suspension of the Seven S4.

Application	Size (thread x length)
Lower radius arm to bushing	7/16" x 3"
Lower radius arm to axle	1/2" x 5"
Axle locating link to bushing	7/16" x 3"
Axle locating link to axle	1/2" x 5"
Axle locating link to center chassis mounting	1/2" x 5"
Upper radius arm to chassis	1/2" x 4" (per side)
Upper radius arm to axle	1/2" x 23/4" (per side)

Shock (damper) to axle	1/2" x 23/4" (per side)
Shock (damper) to chassis	1/2" x 3" with rounded nose (per side)

List of nut and bolts used for the rear suspension of the Lotus Seven S4.

The upper radius links. Right hand upper radius arm bolted to the axle. Right hand upper radius arm bolted to the axle bolted to the rear chassis attachment point. Axle raised into place to allow the attachment to the rear chassis.

Upper radius arms

Two rubber type Y9 bushes are inserted into the axle end of each the upper radius arms (i.e., two for each side). The axle end of the upper radius arm is then pushed into locating ears on the upper side of the rear axle ([\[link\]](#)). With fresh bushings this is a tight fit, and silicone or Teflon grease is helpful in positioning the radius arms to allow the bolt to be inserted through the ears and the bushings ([\[link\]](#)). A nyloc nut is used to hold the upper trailing arm to the rear axle.





The rear axle is carefully jacked up to position so that the upper radius arms can be bolted to the rear chassis using a 4" long $\frac{1}{2}$ " bolt ([\[link\]](#) and [\[link\]](#)). It is worth noting that the bolt for attaching the upper trailing arm to the rear chassis is also used as a chassis-to-body mount.

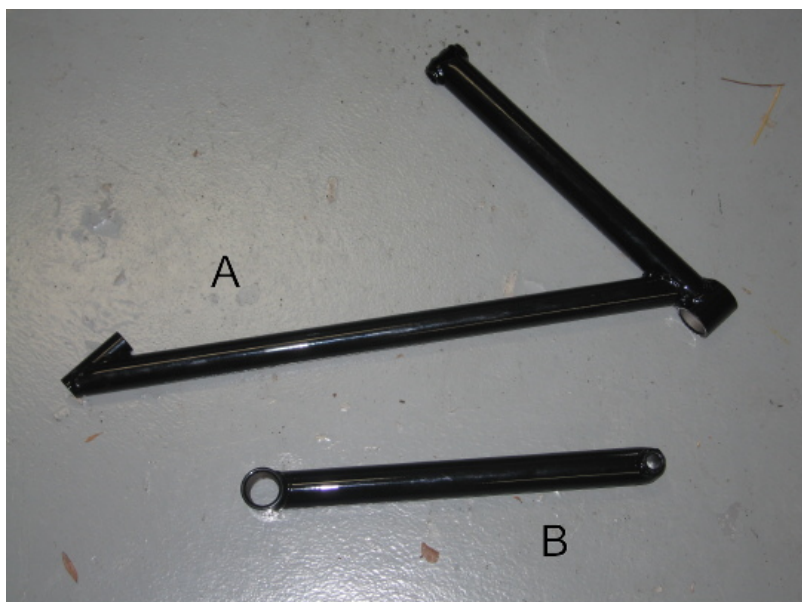


The axle locating link (A) and lower radius arm (B). An example of the type 6000 bushing used for the outer chassis mounts to the lower radius arm and the axle locating link on the Seven S4. The right hand side type 6000 bushing in place in the chassis.

Lower radius arm bolted to the lower attachment point on the axle.

Lower radius arm

The right hand lower radius arm ([\[link\]](#)B) is attached to the chassis via a type 6000 bush ([\[link\]](#)). The bushing is bolted to the chassis from the outside with the larger rubber portion facing towards the center of the chassis ([\[link\]](#)). The axle end of the lower radius arm requires two type Y9 rubber bushings. The lower radius arm is bolted to the lower fixtures in the axle using a bolt and associated nyloc nut ([\[link\]](#)). Washings are used either side of the bushings. The axle will need to be jacked up to an appropriate level in order for the radius arm to be attached to the axle.







The axle locating link bolted to the chassis mounting. View of the axle after attachment via the axle locating link, lower radius arm, and the upper radius arm.

Axle locating link

The axle locating link ([\[link\]](#)A) is bolted to the central chassis mount using a 5" long $\frac{1}{2}$ " bolt with associated nyloc nut ([\[link\]](#)). Two Y9 bushes are located into the chassis mount with appropriate washers. The left hand outer chassis attachment and the axle location for the axle locating link are bolted to the chassis in the same manner as the right hand side lower radius arm ([\[link\]](#)).



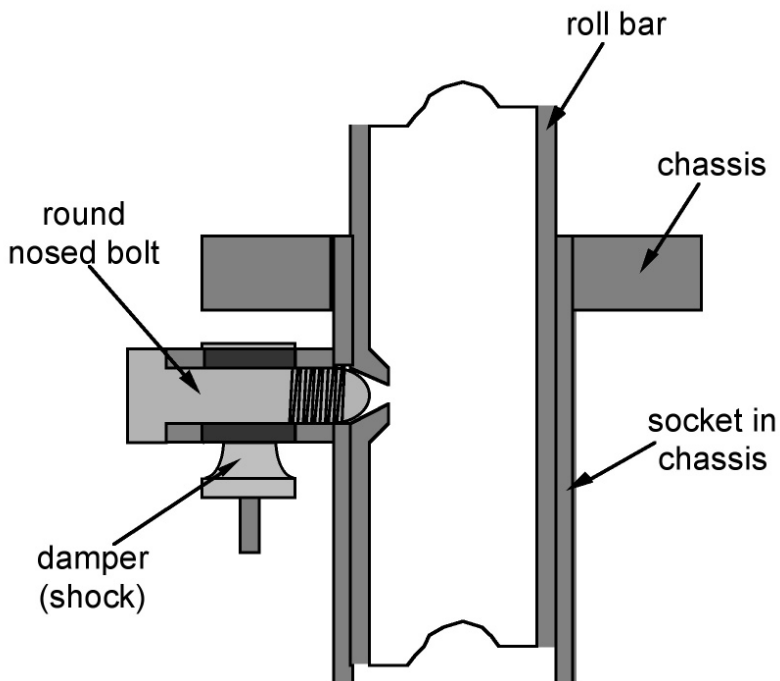
The bolts used for the rear shocks that also hold the roll bar in place showing the rounded ends. Schematic showing the location of the rear upper spring/shock unit mounting combination with the roll bar retention bolt ([\[link\]](#)). Bolts used for the

rear shocks located in position showing the position into which the damper (shock) is attached. View of spring/damper unit after bolting to chassis. View of the left hand rear suspension showing the attachment of the upper radius arm and spring/damper unit. View of installed spring/damper unit and lower and upper radius arms. View of the rear spring/damper in place showing the bump/rebound adjustment.

Spring/damper unit

The upper of the rear spring/damper units are attached to the chassis using a bolt that also holds the roll bar in. The tapered end of each bolt ([\[link\]](#)) fits in a hole in the sidewall of the roll bar ([\[link\]](#) and [\[link\]](#)).





New Spax dampers (Model G655) were purchased from Redline Components, Ltd. As purchased the

dampers (shocks) appear to have excess rubber around the hole associated for the bolt. In order to fit them into both the chassis and the axle it is necessary to remove the excess rubber with a scalpel. Using the tapered bolt the spring/damper units are bolted to the chassis first ([\[link\]](#)). After the axle is jacked into position it is relatively easy to push the lower end of the spring/damper unit into the locating ears on the front side of the axle ([\[link\]](#)). Once the axle is fully attached the jack can be removed ([\[link\]](#)).







The Spax dampers (shocks) have an adjustment knob at the axle end ([\[link\]](#)). This allows for the adjustment of bump and rebound. It is a choice of whether this is positioned towards the front or rear. If it is positioned towards the front of the car, it is easier to reach. However, from experience with a

Series 3 Seven, it is often easier to reach when located at the rear if adjustment is needed while the wheels are on: this is personal bias.



Installed axle after removal of the supporting jack. Installed axle. Right hand rear suspension after installation of the drum, showing the attachment of the upper radius arm, lower radius arm, and spring/damper unit. The right hub bolted in place with two lug nuts for reference.

Drums and final installation

Additional views of the installed rear axle are shown in [\[link\]](#) and [\[link\]](#).





Ordinarily, at this point it is appropriate to install the rear brake shoes and the associated hardware. In the present case given the timetable for the restoration the drums were bolted back into location ([\[link\]](#) and [\[link\]](#)). This will allow the wheels to be attached.





Resources

- Redline Components, Ltd. Timber Hall, 19 Timber Lane, Caterham, Surrey, CR3 6LZ, UK. Tel: +44 (0)1883 346515.

www.redlinecomponents.co.uk.

- Spax Performance, Ltd. Spax House, Murdock Road, Bicester, Oxfordshire, OX26 4PL, UK. Te: + 44 (0)1869 244771. www.spax.co.uk.

Rolling Chassis

Once both the front and rear suspension components were attached to the chassis temporary wheels and tires were mounted ([\[link\]](#)). For ease of movement, transportation wheels with narrow tires were fitted. These are usually used when a Lotus Type 61 Formula Ford is being transported. [\[link\]](#) – [\[link\]](#) show various views of the rolling chassis. View of chassis with wheels mounted.



Front view of rolling chassis. Note the outer links of the front sway bar are not attached to the dampers.



Left hand view of rolling chassis with the Lotus Type 61 Formula Ford in the background.



Rear view of rolling chassis. Note the rear axle appears to be angled upwards due to lack of weight with no body.



Right hand view of rolling chassis.



Restoration of the Wheels and Choosing Tires

The Lotus Seven S4 (Type 60) was provided standard with 5 1/2" x 13" pressed steel 'bolt-on' wheels with chromium plated hub-caps ([\[link\]](#)). As an upgrade 5 1/2" x 13" light alloy 'bolt-on' Brand Lotus rims were available at extra cost ([\[link\]](#)). Both wheels were supplied with either 165 x 13" Dunlop SP Sport or Goodyear G800 radial tires as standard. A Seven S4 fitted with the pressed steel 'bolt-on' wheels with chromium plated hub-caps.



A view of the Brand Lotus wheels as fitted to the Seven S4.



One of the fire damaged Brand Lotus alloy wheels. The Brand Lotus alloy wheel used as the spare. A copy of the original advertising for the Brand Lotus wheels (Lotus Cars, Ltd.). View of coated and finished wheels as finished by Wheel Wizard (www.wheelwizard.com). View of coated and finished wheels as finished by Wheel Wizard (www.wheelwizard.com). One of the new lug nuts (A) with its collar in comparison with (B) two of the original items with and without the collar.

Wheel restoration

Several of the tires on LBS4/2894/GT had burst as a result of fire damage, and all of the road wheels showed smoke damage ([\[link\]](#)). No physical damage appears to have occurred as a consequence of the

fire; however, one of the wheels shows some indication of damage due to curbing. As a consequence of being mounted at the back of the car and hence the furthest from the fire, the spare wheel showed only limited damage other than that expected for a wheel of its age ([\[link\]](#)).





Each wheel was initially media blasted to clean of all the paint and fire damage in order to determine whether any structural damage occurred; however, the wheels appear suitable to use for street applications.

It is never advised to use “original” wheels for racing applications. New steel or alloy wheels should be used for any track, rally, or race uses.

The wheels were cleaned, polished, painted, and clear coated by Wheel Wizard (www.wheelwizard.com) in order to return them to

the original style ([\[link\]](#)). One of the finished wheels is shown in [\[link\]](#) and [\[link\]](#).

The Brand Lotus Wheel



**a
truly precision
product**



Lug nuts

The original lug nuts were damaged by age and

possibly the fire. The stud has a right hand pitch of 7/16" x 20 and replacement items are available from Redline Components, Ltd ([\[link\]](#)).



The tread pattern on the Kumho Solus KE21. The tread pattern on the Kumho 722. View of the sidewall and tread pattern on the Michelin Defender. The tread pattern on the Sumitomo HTR

T4. View of one of the restored Brand Lotus wheels with a Sumitomo HTR T4 mounted.

Tires

The original size tires were 165/70 x 13”.

Unfortunately, in the US this size is not as readily obtained, and so an alternative size was chosen.

However, it is important when choosing alternative tire sizes that the overall rolling diameter is kept as consistent so that the speedometer reads correctly. A useful tool for choosing alternative tire sizes is provided on the www.Miata.net web site. It allows for the calculation of diameter, circumference, and speedometer correction when comparing two different sizes of tire. [\[link\]](#) shows the comparison of the original size and potential sizes of available tires.

Specification	Side wall (in)	Diameter (in)	Circumference (in)	Difference (%)
165/70-13	134.5	22.1	69.4	n/a
175/65-13	134.5	22.0	69.0	+ 0.6
175/70-13	134.8	22.6	71.1	-2.5

Comparison of original specification (165/70-13)

versus potential alternative sizes. Note: a negative difference results in the speedometer reading higher than with the stock tires.

Based upon this program it was decided to use the 175/70-13. Tire Rack (www.tirerack.com) stocked a small selection of this size including the Kumho Solus KE21 ([\[link\]](#)) and 722 ([\[link\]](#)), the Michelin Defender ([\[link\]](#)), and the Sumitomo HTR T4 ([\[link\]](#)).









Since all the tires available have a similar tread pattern, and the tires will simply be used for storage during the restoration and for initial testing, it was decided to use a set of Sumitomo HTR T4. [\[link\]](#) shows a view of one of the tires mounted on the restored wheel.



Resources

- Wheel Wizard, 3695 Longview Drive, Atlanta, GA 30341, USA. Tel: +1 770 451 6333.
www.wheelwizard.com.
- Moss Motors, Ltd. 440 Rutherford Street, Goleta, CA 93117, USA. Tel: +1 800 667 7872 or +1 805 681 3400. www.mossmotors.com.
- Tire Rack, 7101 Vorden Parkway, South Bend, IN 46628. Tel: +1 888 541 1777.
www.tirerack.com.

Bibliography

- D. Ortenburger, *Legend of the Lotus Seven*, Mercian Press (1987).
- J. Coulter, *Lotus Seven*, Amadeus Press (1995).
- Miata.net Tire Size Calculator. www.miata.net/garage/tirecalc.html.

The Steering Rack

For the Series 4 Lotus Seven the Triumph Spitfire rack previously used in the Series 3 was replaced with one sourced from Burman. The turning circle remained excellent with $2\frac{3}{4}$ turns lock-to-lock.

The steering rack in LBS4/2894/GT appeared to be still functioning despite the rubber gaiters being destroyed ([\[link\]](#)). However, the rubber mounts were beyond use and alternatives would be needed. The first approach was going to be reconditioning and rebuilding the rack. However, it was found that the threaded nut that holds the track rods into the rack body were stripped due to corrosion, and there was no way to remove them without cutting them. Thus, before drastic surgery was contemplated an alternative was investigated.

View of the steering rack and one of the original fire damaged rubber mounts.



While this particular version of the rack is no longer available, it is essentially the same rack as used on the Mk1 and Mk2 Ford Escort. Since these were sold in vast numbers, there are new replacements available. [\[link\]](#) shows the left hand drive 2.4 Ratio Escort Mk2 short stem steering rack available from Motorsport Tools, Ltd. (www.motorsport-tools.com). As may be seen by comparing [\[link\]](#) and [\[link\]](#) the racks are similar but with a difference in the steering column shaft (stem) length and potentially in the track rod lengths. However, both of these may be easily modified for the Seven S4 application. View of as supplied brand new manufactured 2.4 ratio Escort Mk2 short stem steering rack.
Copyright: Motorsport Tools, Ltd. (2011).



The new rack was disassembled and the joint to the steering column and track rod ends adapted to the Seven S4 application by Lucas Racing and Restoration (www.lucasracinginc.com).

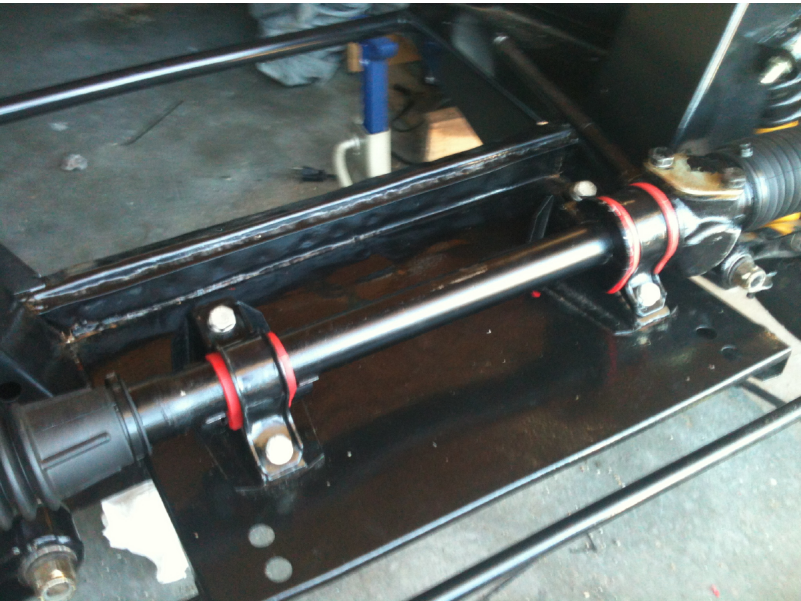
View of the rack clamps after media blasting and powder coating and the new Polyrace steering rack mounts. View of the new rack bolted into the chassis. View of replacement track rod end.

Instillation

The rack clamps were media blasted and then powdered coated by Custom Coatings ([\[link\]](#)). While suitable rubber mounts are available from Motorsport Tools, Ltd., it was decided to use Polyrace steering rack bushes mounts from the same source ([\[link\]](#)).



The Polyrace bushes were positioned on the rack and the rack bolted to the repaired mount ([\[link\]](#)). The bolts were tightened down sequentially to ensure an even



Track rod ends (steering arms)

The original track rod ends were badly damaged in the fire and so new units were purchased from Motorsport Tools, Ltd. ([link]). While the final alignment will be performed once the car is complete, it was decided to roughly align in order to ease movement of the car. As a consequence no lock nuts were used for the track rod ends.



Resources

- Motorsport Tools UK Ltd., Llithfaen, Pwllheli, Gwynedd, LL53 6NH, Wales, UK. Tel: +44 (0)175 8750000. <http://www.motorsport-tools.com>.

- Lucas Racing and Restoration, 10030 Talley Lane, Houston, Texas 77041, USA. Tel: +1 713 462 0068. www.lucasracinginc.com.
- Custom Coatings, 16219 Dundee, Cypress, TX 77429, USA. Tel: +1 281 813 0119.

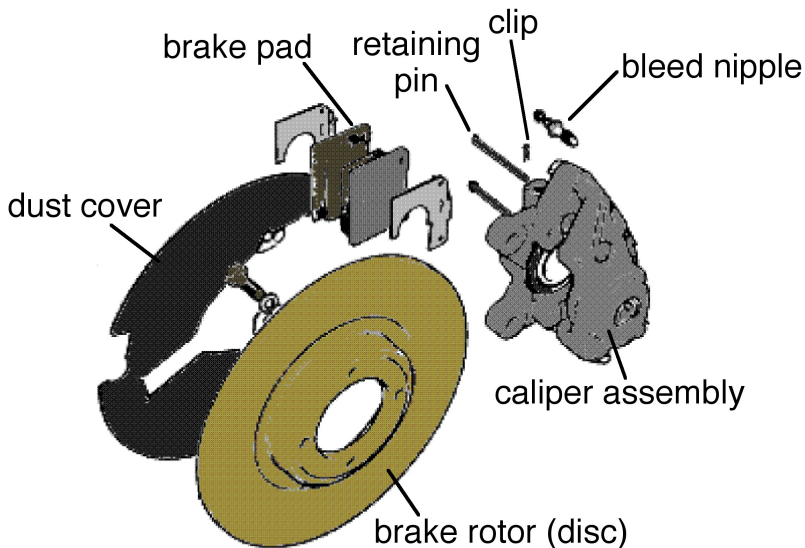
Bibliography

- D. Ortenburger, *Legend of the Lotus Seven*, Mercian Press (1987).
- J. Coulter, *Lotus Seven*, Amadeus Press (1995).

Restoring The Front Brake Calipers

As is common for many 1960's and 70's Lotus cars, the front brake calipers are Girling 14LF. These were widely used over this period by domestic manufacturers such as Ford and Triumph. A schematic of the caliper and brake assembly is shown in [\[link\]](#).

Schematic representation of the Girling sourced front brakes.



Used piston boot and retaining clip. One of the new pistons (A) and an original piston (B). The caliper assemblies after removal of the pistons and all seals.

Disassembly and cleaning

The brake pads are removed by releasing the clips from the retaining pins. The pins are then slid out of

the caliper assembly, at which point the pads are removed out the back of each assembly. Using a screwdriver, the old piston boots are removed along with their retaining clips ([link](#)).



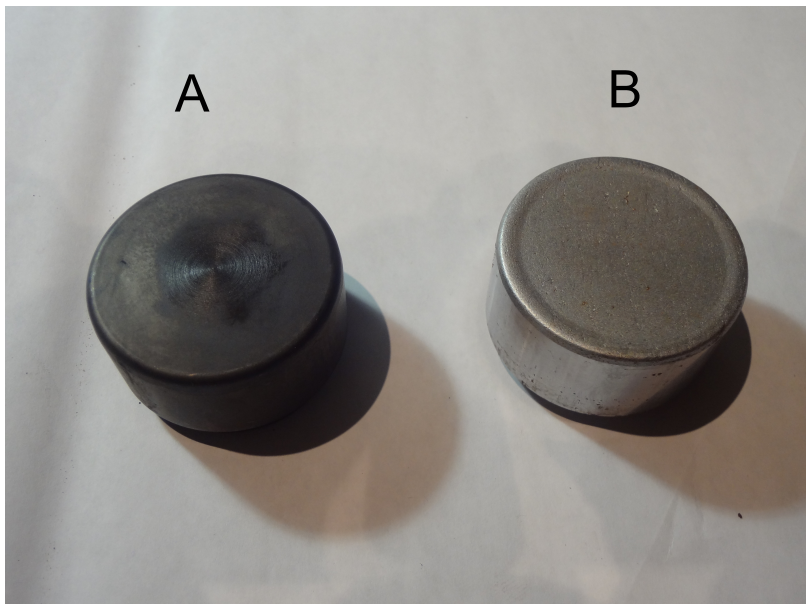
The pistons can then be removed by connecting the brake caliper to a compressed air source. Placing the caliper assembly into a bench vice and putting an old glove or towel between the pistons, the air is introduced into the caliper. Unless the piston is rusted in place, one or both should be released from their respective barrels.

Under no circumstances should fingers or any body part be placed in the caliper while removing the pistons with compressed air. **Correct safety**

glasses and gloves should be work while attempting to remove the pistons.

Unfortunately, in many cases only one of the pistons is removed. If this occurs, the two halves of the caliper assembly must be separated. It is important not to loose the rubber O-ring that is positioned between the caliper halves, since this is not included in most rebuild kits. The half with the piston in is then subjected to air pressure, while the hole that connects the two halves (for brake fluid passage) is covered by a glove or similar. In the present case this resulted in the piston being only partially removed from the caliper assembly, and additional force was applied using vice grips. Due to difficulties in removing the pistons from the caliper assembly, the outer face (barrel) of the pistons was damaged ([\[link\]](#)). Given that a seal between piston and the caliper assembly is required, it was decided that it would be easier to replace the pistons.

The piston should be pointed away from persons or breakable items since under pressure it can be expelled with violent force. Placing a blanket over the assembly is advised. Correct safety glasses and gloves should be work while attempting to remove the pistons.



Finally, the rubber seals inside the caliper barrels are removed using a sharp point or a small screwdriver. The two halves of the caliper assembly ([\[link\]](#)) are ready for cleaning. The caliper bodies were Teflon® coated by PolyDyne Performance Coatings. The coating was chosen to allow for the ease of cleaning and removal of brake dust that ordinarily builds up on any suspension components.



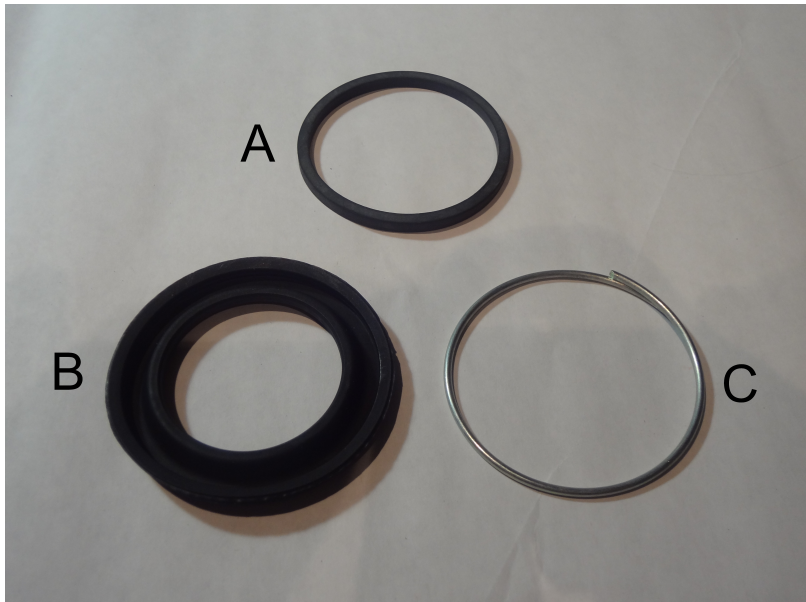
Contents of the caliper rebuild kit. One each of the piston seal (A), piston boot (B), and retaining clip (C). View of the inside of one half of the caliper showing the location of the piston seal (arrowed). One half of a caliper showing the installed piston, with its boot and retaining clip. The small rubber washer (not supplied in the rebuild kit) that seals the two halves of the caliper. View of one of the finished calipers, showing the four bolts that hold the two halves together. One of the finished calipers showing the brake pad pins and retaining clips. Both calipers reassembled.

Assembly

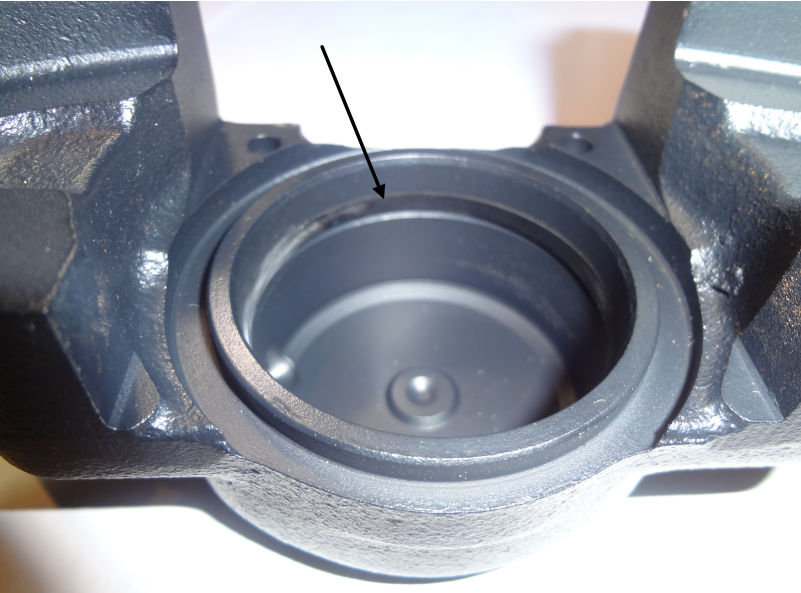
The calipers were rebuilt using a TRW rebuild (SP2697) kit from Moss Motors. The rebuild kit

consists of 4 piston boots, 4 rubber seals, 4 retaining clips, and 2 rubber dust caps ([\[link\]](#) and [\[link\]](#)). One part that does not come in the kit and therefore has to be reused is the rubber washer that seals between the two halves of the caliper. This must be retained from the original; however, all other seals are disposable.





The first task is to install the rubber seal ([\[link\]](#)A) inside the caliper. The ring is fed into the groove inside the barrel of the caliper, taking care not to damage or twist it ([\[link\]](#)). One piston is then installed into each of the caliper halves. It is important to push the piston in straight. In order to ease the piston in, the rubber seal and caliper barrel are greased. A small amount of silicone vacuum grease is suitable, although if none is available, a light rub with break fluid will also work. Once the pistons are fully pressed into the caliper, the piston boot ([\[link\]](#)B) is stretched over the piston and fitted to the caliper with the retaining clips ([\[link\]](#)C). The final result is shown in [\[link\]](#).



Before the two caliper halves are joined, it is important not to forget the rubber washer that seals the fluid passage between the two halves of the caliper ([\[link\]](#)). With this in place the two halves

are bolted together ([\[link\]](#)).



Since brake pads will not be installed until the calipers are fitted to the upright/hub/disk combination, the pad retaining pins and clips are

fitted to ensure they do not get lost ([\[link\]](#)). A view of the finished calipers is shown in [\[link\]](#), including the rubber dust caps in place over the bleed screws.



Resources

- PolyDyne Performance Coatings, 11211 Neeshaw Drive, Houston, Texas 77065, USA. Tel: +1 888 765 9396 or +1 281 894 6382. www.polydyn.com.
- Moss Motors, Ltd. 440 Rutherford Street, Goleta, CA 93117, USA. Tel: +1 800 667 7872 or +1 805 681 3400. www.mossmotors.com.

Installation of the Front Brake Calipers

Photograph of German physicist Gerd Binnig (left) and Swiss physicist Heinrich Rohrer (right).

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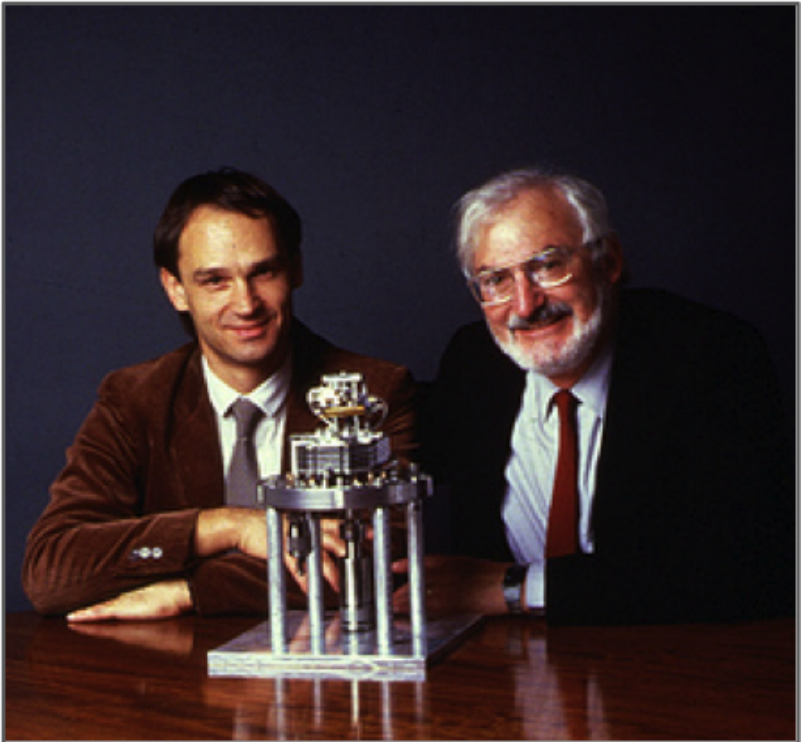
H. Kumar Wickramasinge, now a professor at the University of California, Irvine. Reproduced from “H. Kumar Wickramasinge.” UCI Samueli, University of California, Irvine. Copyright The Henry Samueli School of Engineering, 2017.

Nobelprize.org. Nobel Media AB, 2017. Copyright Nobel Media AB 2017. This image shows a typical MFM setup. Reproduced with permission from A. Méndez-Vilas, *Modern research and educational topics in microscopy. Vol. 2: Applications in physical/chemical sciences, techniques*. Formatex, Badajoz (2007).. Copyright: FORMATEX 2007. Illustration of an MFM tip on the instrument cantilever.

Introduction

Magnetic force microscopy (MFM) is a natural extension of scanning tunneling microscopy (STM), whereby both the physical topology of a sample surface and the magnetic topology may be seen. Scanning tunneling microscopy was developed in 1982 by Gerd Binnig and Heinrich Rohrer, and the two shared the 1986 Nobel prize for their innovation. Binnig later went on to develop the first

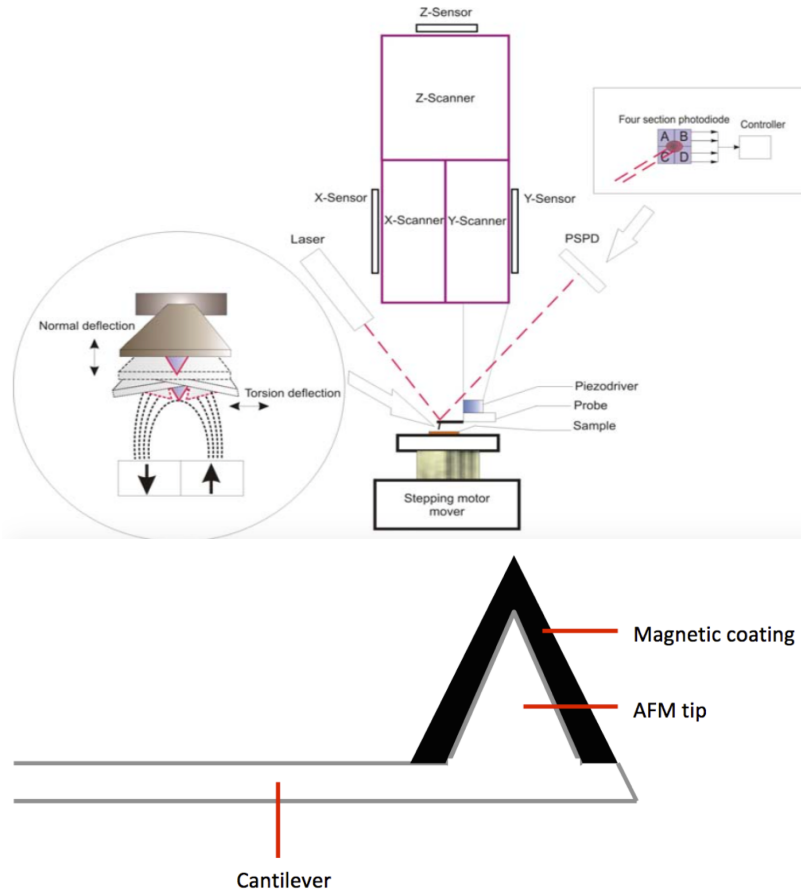
atomic force microscope (AFM) along with Calvin Quate and Christoph Gerber ([\[link\]](#)). Magnetic force microscopy was not far behind, with the first report of its use in 1987 by Yves Martin and H. Kumar Wickramasinge ([\[link\]](#)). An AFM with a magnetic tip was used to perform these early experiments, which proved to be useful in imaging both static and dynamic magnetic fields.





MFM, AFM, and STM all have similar instrumental setups, all of which are based on the early scanning tunneling microscopes. In essence, STM uses a very small conductive tip attached to a piezoelectric cylinder to carefully scan across a small sample space. The electrostatic forces between the conducting sample and tip are measured, and the output is a picture that shows the surface of the sample. AFM and MFM are essentially derivative types of STM, which explains why a typical MFM device is very similar to an STM, with a piezoelectric driver and magnetized tip as seen in

[\[link\]](#) and [\[link\]](#).

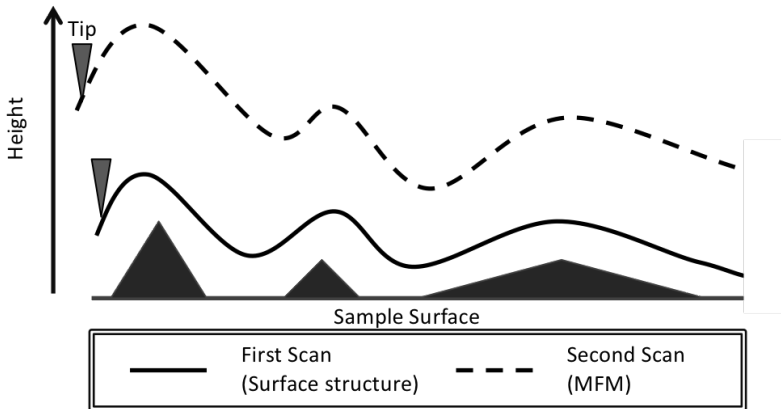


One may notice that this MFM instrument very closely resembles an atomic force microscope, and this is for good reason. The simplest MFM instruments are no more than AFM instruments with a magnetic tip. The differences between AFM and MFM lie in the data collected and its processing. Where AFM gives topological data through tapping, noncontact, or contact mode, MFM gives both topological (tapping) and magnetic topological

(non-contact) data through a two-scan process known as interleave scanning. The relationships between basic STM, AFM, and MFM are summarized in [\[link\]](#).

Technique	Samples	Qualities Observed	Mode	Benefits	Limitations
MFM	Any film or powder surface; magnetic domains;	Electrostatic interactions; forces; van der Waals' interactions; topology; morphology	Tapping; non-contact	Magnetic and physical properties; high resolution	Resolution depends on tip size; different tips for various applications; complicated data processing and analysis
STM	Only conductive surfaces	Topology; morphology	Constant height; constant current	Simplest instrumentation; many variations	Resolution depends on tip size; tips wear out easily;

experiment, and this gives the surface topology of the sample. Then, a second scan is taken in non-contact mode, where the magnetic force exerted on the tip by the sample is measured. These two types of scans are shown in [\[link\]](#).

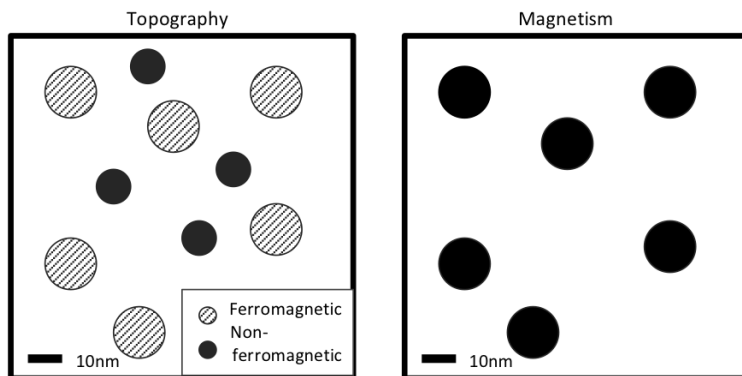


In non-contact mode (also called dynamic or AC mode), the magnetic force gradient from the sample affects the resonance frequency of the MFM cantilever, and can be measured in three different ways.

- Phase detection: the phase difference between the oscillation of the cantilever and piezoelectric source is measured
- Amplitude detection: the changes in the cantilever's oscillations are measured
- Frequency modulation: the piezoelectric source's oscillation frequency is changed to maintain a 90° phase lag between the cantilever and the piezoelectric actuator. The

frequency change needed for the lag is measured.

Regardless of the method used in determining the magnetic force gradient from the sample, a MFM interleave scan will always give the user information about both the surface and magnetic topology of the sample. A typical sample size is $100 \times 100 \mu\text{m}$, and the entire sample is scanned by rastering from one line to another. In this way, the MFM data processor can compose an image of the surface by combining lines of data from either the surface or magnetic scan. The output of an MFM scan is two images, one showing the surface and the other showing magnetic qualities of the sample. An idealized example is shown in [\[link\]](#).



Types of MFM tips

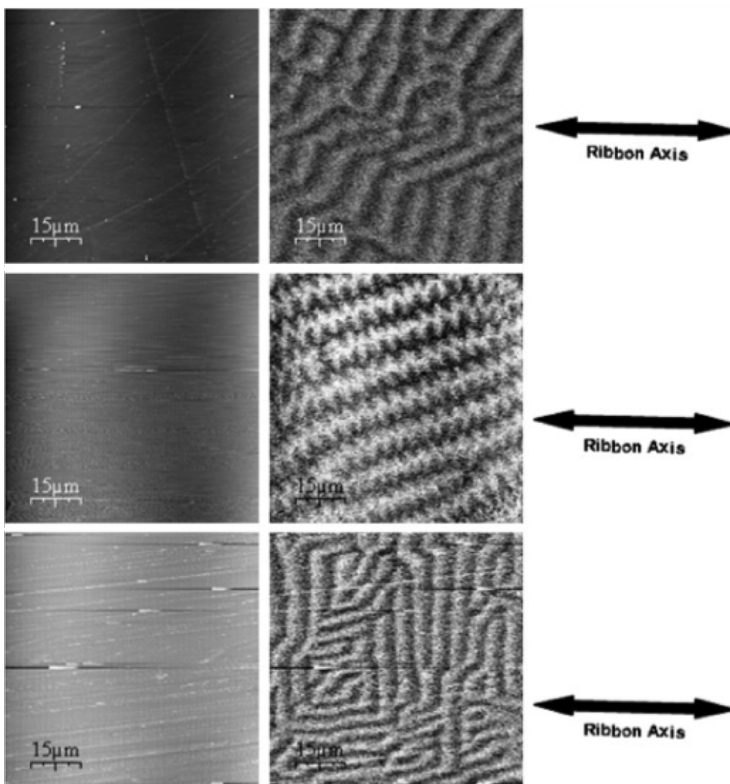
Any suitable magnetic material or coating can be used to make an MFM tip. Some of the most commonly used standard tips are coated with FeNi,

CoCr, and NiP, while many research applications call for individualized tips such as carbon nanotubes. The resolution of the end image in MFM is dependent directly on the size of the tip, therefore MFM tips must come to a sharp point on the angstrom scale in order to function at high resolution. This leads to tips being costly, an issue exacerbated by the fact that coatings are often soft or brittle, leading to wear and tear. The best materials for MFM tips, therefore, depend on the desired resolution and application. For example, a high coercivity coating such as CoCr may be favored for analyzing bulk or strongly magnetic samples, whereas a low coercivity material such as FeNi might be preferred for more fine and sensitive applications.

Data output and applications

From an MFM scan, the product is a 2D scan of the sample surface, whether this be the physical or magnetic topographical image. Importantly, the resolution depends on the size of the tip of the probe; the smaller the probe, the higher the number of data points per square micrometer and therefore the resolution of the resulting image. MFM can be extremely useful in determining the properties of new materials, as in [\[link\]](#), or in analyzing already known materials' magnetic landscapes. This makes MFM particularly useful for the analysis of hard drives. As people store more and more information

on magnetic storage devices, higher storage capacities need to be developed and emergency backup procedures for this data must be developed. MFM is an ideal procedure for characterizing the fine magnetic surfaces of hard drives for use in research and development, and also can show the magnetic surfaces of already-used hard drives for data recovery in the event of a hard drive malfunction. This is useful both in forensics and in researching new magnetic storage materials.



MFM has also found applications on the frontiers of research, most notably in the field of Spintronics. In

general, Spintronics is the study of the spin and magnetic moment of solid-state materials, and the manipulation of these properties to create novel electronic devices. One example of this is quantum computing, which is promising as a fast and efficient alternative to traditional transistor-based computing. With regards to Spintronics, MFM can be used to characterize non-homogenous magnetic materials and unique samples such as dilute magnetic semiconductors (DMS). This is useful for research in magnetic storage such as MRAM, semiconductors , and magnetoresistive materials.

MFM for characterization of magnetic storage devices

In device manufacturing, the smoothness and/or roughness of the magnetic coatings of hard drive disks is significant in their ability to operate. Smoother coatings provide a low magnetic noise level, but stick to read/write heads, whereas rough surfaces have the opposite qualities. Therefore, fine tuning not only of the magnetic properties but the surface qualities of a given magnetic film is extremely important in the development of new hard drive technology. Magnetic force microscopy allows the manufacturers of hard drives to analyze disks for magnetic and surface topology, making it easier to control the quality of drives and determine which materials are suitable for further research. Industrial competition for higher bit density (bits

per square millimeter), which means faster processing and increased storage capability, means that MFM is very important for characterizing films to very high resolution.

Conclusion

Magnetic force microscopy is a powerful surface technique used to deduce both the magnetic and surface topology of a given sample. In general, MFM offers high resolution, which depends on the size of the tip, and straightforward data once processed. The images outputted by the MFM raster scan are clear and show structural and magnetic features of a $100 \times 100 \mu\text{m}$ square of the given sample. This information can be used not only to examine surface properties, morphology, and particle size, but also to determine the bit density of hard drives, features of magnetic computing materials, and identify exotic magnetic phenomena at the atomic level. As MFM evolves, thinner and thinner magnetic tips are being fabricated to finer applications, such as in the use of carbon nanotubes as tips to give high atomic resolution in MFM images. The customizability of magnetic coatings and tips, as well as the use of AFM equipment for MFM, make MFM an important technique in the electronics industry, making it possible to see magnetic domains and structures that otherwise would remain hidden.

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Engine Rebuild

For those wishing to complete the task themselves, the best guide is the book by Peter and Valerie Wallage, *Rebuilding and Tuning Ford's Kent Crossflow Engine*. This is a great book for anyone interested in the Kent motors. I have previously used this as a guide in rebuilding a race motor for a 1969 Lotus Type 61 Formula Ford. In addition, Jake Lamont and Tom Andresen's book entitled *How to Build and Maintain Competitive (yet legal) Formula Ford 1600 Engines*, is a useful source, although more limited to Formula Ford motors to Sports Car Club of America (SCCA) racing rules. In the present case, for time limitations, it was decided to have the engine rebuilt by Farley Engines, Inc. The company owner, Curtis Farley, is one of the most respected names in building racing and performance engines in the US.

Engine after removal from the chassis. View of the original oil pump with the remains of the molten distributor. View of the original oil pump. Removed oil pump. View of the thermostat housing. View of the thermostat. View inside the water channel in the head. View of the original head and rocker shaft. Copyright: Curtis Farley (2013). View of the double valve springs. Copyright: Curtis Farley (2013). View inside the intake. View of one of the pistons and one of the intake valves showing the residual aluminum metal from the melted Weber carburetor. Copyright: Curtis Farley (2013). View of one of the pistons and one of the intake valves after removal of the

aluminum metal from the melted Weber carburetor.
Copyright: Curtis Farley (2013).

Disassembly

[\[link\]](#) shows the engine after removal from the chassis. Prior to shipping the engine to Farley Engines some preliminary stripping was required for shipping. The oil pump and filter bracket was destroyed as a result of the distributor melting onto it ([\[link\]](#)): it was therefore, removed ([\[link\]](#) and [\[link\]](#)).







The thermostat housing ([\[link\]](#)) was badly corroded to it was removed, as was the thermostat itself ([\[link\]](#) and [\[link\]](#)). The corrosion of the water passage was no more than expected from an engine of this age, offering hope that no internal damage had been done by the fire.







Disassembly of the engine indicated that at some point in its history it had been head ported ([\[link\]](#)) with dual valve springs installed ([\[link\]](#)). In addition, +.020 pistons had been fitted and a high lift cam. All of these modifications would have significantly increased the power over the stock Cortina motor. Interestingly a lightweight alloy

flywheel had also been fitted in place of the standard unit.



It was known that the carburetor had melted and run down the intake manifold. Removal of the

manifold showed that some molten metal had run into the engine past at least one of the intake valves ([\[link\]](#)). One result of the complete tear-down was that it was possible to see the location where the molten aluminum from the carburetor had flowed through the intake valve and onto the piston ([\[link\]](#) and [\[link\]](#)).





Replacement sump showing the additional baffling. This was originally used for the 1969 Lotus Seven S3 prior to conversion to dry sump. Close up view of the baffles inside the replacement sump. The original and replacement intake manifolds.

New and replacement parts

In addition to a complete rebuild of the block and head, several components were replaced by either new or used items. Since the 1600 Ford crossflow engine installed in my 1969 Lotus Seven S3 had been converted to dry-sump for racing several components were known to be in good working order and used for the present engine. The replacement items included:

- Oil pump.
- Water pump and pulley.
- Sump.
- Oil strainer and suction pipe.
- Weber 32DFM twin choke downdraught carburetor.

In addition, the mechanical fuel pump was to be replaced by an electric item so a blanking plate sourced from Dave Bean Engineering. The reason for replacing the sump was that while the external dimensions are the same as the original, the one used on the Seven S3 had baffles welded inside to minimize oil surge ([\[link\]](#) and [\[link\]](#)). Even though it is intended that the Seven S4 were to be used for the street (rather than racing) the additional baffling should provide added protection for the engine against oil starvation.



Finally, the intake manifold had been significantly damaged due to the carburetor melting through it ([\[link\]](#)). An unused manifold was amongst the spares when I purchased the Lotus Type 61 Formula

Ford (also shown in [\[link\]](#)). At some time the manifold had been port matched to the engine and significantly flowed. Unfortunately, the previous owner had used the car for auto-cross (auto testing) in which the regulations are different from Monoposto (www.monoposto.com) and SCCA (www.scca.org) Formula Ford racing in which such modifications are not allowed. However, there is no issue with its use for the street, and it was decided to use this as a direct replacement although any power gain will be negligible.

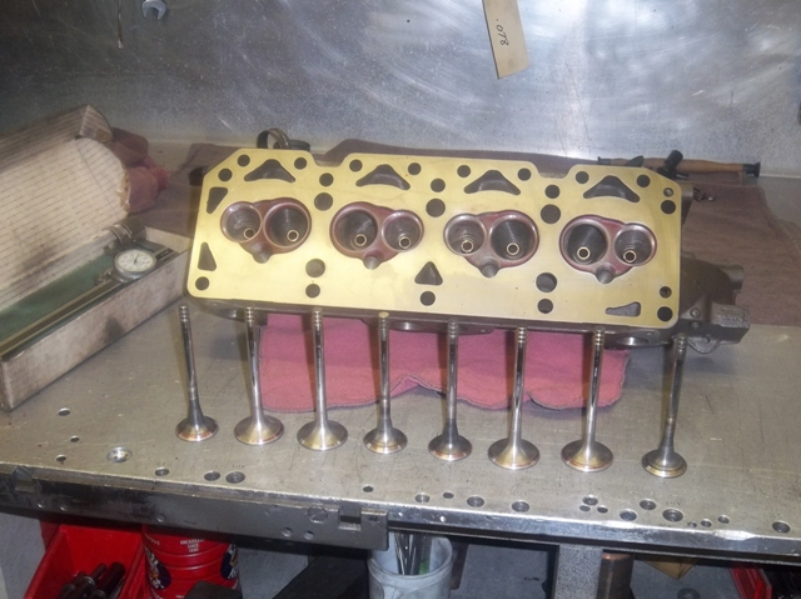


View of the bottom end of the engine during the rebuild. Copyright: Curtis Farley (2013). A view of the reconditioned head and valves ready for fitting. Copyright: Curtis Farley (2013).

Upgrades

Since the engine was an original Cortina unit rather than the later upgraded unit, it was decided to upgrade the main caps. In addition, the need to run unleaded fuel meant that hardened valve seats were to be installed, while up-rated valves were fitted at the same time. The original camshaft was a higher performance item than stock; however, it was badly worn. So it was decided to replace it with a Kent Cams fast road cam (model BCF2). This had been previously used in the 1600 cc Kent engine used in my 1969 Seven S3.

Due to the damage associated with the molten alloy flowing into the engine through the intake valves it was decided to bore the block for +.030 pistons by AE (Dave Bean Engineering). The lifters were reground and hardened by Elgin Industries (www.elginind.com). New valve springs were sourced from Burton Power (www.burtonpower.com). [\[link\]](#) shows a view of the engine in progress, while [\[link\]](#) shows a view of the head ready for instillation.



View of the left hand side of the rebuilt engine. The exhaust ports are covered with tape to preclude contamination during shipping and storage. Note the top dead center (TDC) mark on the fly wheel. View of the top of the rebuilt engine showing the

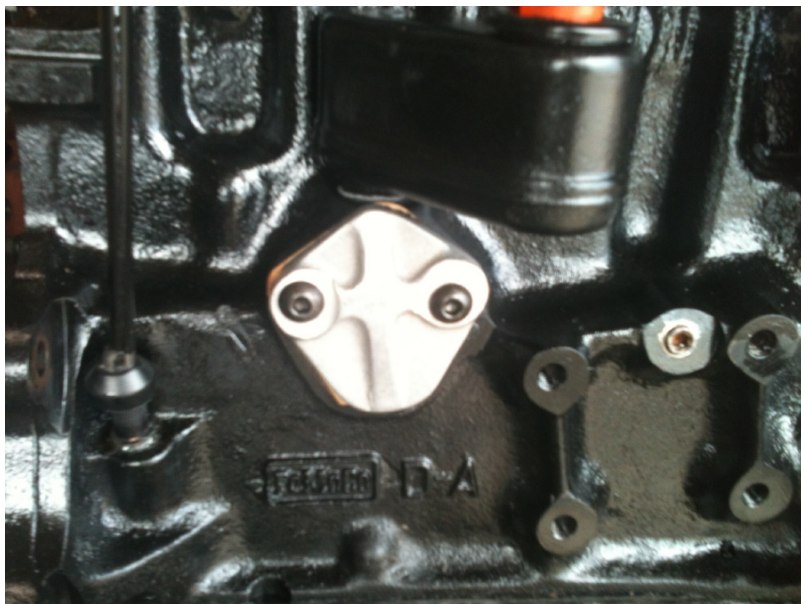
intake manifold, rocker cover and spark plugs. View of the right hand side of the rebuilt engine showing the oil pump, oil filter, and the 123 ignition system. View of the blanking plate covering the original location of the mechanical fuel pump. The dyno data. A graph showing the power and torque as a function of engine rpm.

Finished engine

The finished engine is shown in [\[link\]](#) – [\[link\]](#). The blanking plate for the fuel pump is shown in [\[link\]](#).







[\[link\]](#) shows a summary of the relevant measurements for the rebuilt engine. [\[link\]](#) shows the dyno sheet for the finished engine, while the appropriate data is shown graphically in [\[link\]](#).

Bore	3.221 in
Stroke	3.06 in
Displacement	1634.391 cc
Main bearing clearance	0.0025 in
Rod bearing clearance	0.002 in
Piston/cylinder clearance	0.004 in
Head gasket thickness	0.04 in (5.34 cc)

(volume)

Compression ratio	9.56
Intake valve clearance	0.008
Exhaust valve clearance	0.013
Cam timing intake	106° ATDC
Cam timing exhaust	110° BTDC
Intake valve lift @ overlap	0.075 in
Exhaust lift @ overlap	0.06 in
Ignition timing	38° full advance

Specifications for finished Ford Cortina 1600 cc engine.

Farley Engines
14025 92 Highway
Platte City, MO 64079
(816) 431-3550
(816) 431-3548 FAX

Test Number: 5
Date (M/D/Y): 3/20/82 Time (H:M:S): 31:25:20 Operator: C. Farley
Engine Description: Ford New Series Lotus 7 Combine Engine
Test description: STD Test

Test: 500 RPM Step Test	Fuel Spec. Grav.: .715	Air Sensor: 6.5
Vapor Pressure: 1.37	Barometric Pres.: 29.41	Ratio: 1.00 TO 1
Engine Type: 4-Cycle Spark	Engine displacement: 99.7	Stroke: 3.060

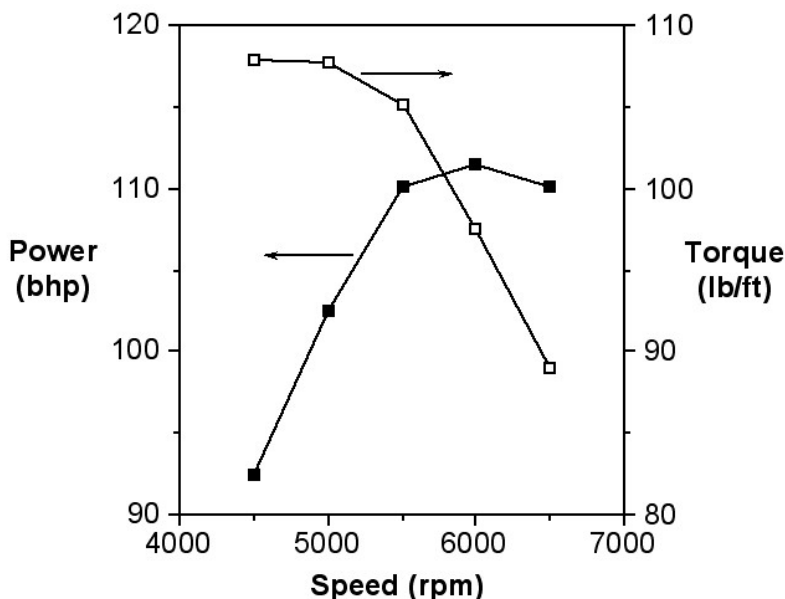
Speed	Trq	Pwr	FA	A1	A/F	BSFC	BSAC	Man-P	Oil	CAT	Fuel	Oil	Wat
rpm	lb-ft	hp	lb/hr	scfm		lb/Hphr	In Hg	psi	F	F	Out	Out	
4500	97.7	83.7	38.4	104.5	12.5	.46	5.73	.0	36.4	80	0	165	178
5000	97.1	92.4	44.1	113.7	11.8	.48	5.65	.0	36.8	83	0	167	178
5500	94.6	99.1	48.1	121.7	11.6	.49	5.64	.0	36.9	83	0	170	174
6000	87.7	100.2	52.0	129.9	11.5	.52	5.95	.0	36.8	81	0	174	177
6500	79.7	98.6	55.8	135.6	11.2	.57	6.31	.0	37.0	82	0	175	178

Data from computer disk file - (BARON313)

Standard Corrected Data for 29.92 inches Hg. 60 F dry air Test# 5

Test: 500 RPM Step Test	Fuel Spec. Grav.: .715	Air Sensor: 6.5
Vapor Pressure: 1.37	Barometric Pres.: 29.41	Ratio: 1.00 TO 1
Engine Type: 4-Cycle Spark	Engine displacement: 99.7	Stroke: 3.060

RPM	CBT	CBMP	FHP	VEX	MEX	FA	A1	A/F	BSFC	CAT	Oil	Wat	BSAC
	Lb-ft					Lb/Hr	scfm			F	Out	Out	
4500	107.8	92.4	18.2	89.1	83.8	38.4	104.5	12.5	.46	80	165	178	5.73
5000	107.7	102.5	19.5	87.8	82.6	44.1	113.7	11.8	.48	83	167	178	5.65
5500	105.1	110.1	23.0	85.5	81.1	48.1	121.7	11.6	.49	83	170	174	5.64
6000	97.5	111.4	26.8	83.4	78.9	52.0	129.9	11.5	.52	81	174	177	5.95
6500	89.0	110.1	31.1	80.4	76.0	55.8	135.6	11.2	.57	82	175	178	6.31



Resources

- Farley Engines, Inc., 14025 State Rte 92, Platte City, MO 64079, USA. Tel: +1 816 431 3550.
- Burton Power, Ltd., 617-631 Eastern Avenue, Ilford, Essex, IG2 6PN, UK. Tel: +44 (0) 20 8518 9136. www.burtonpower.com.
- Dave Bean Engineering, Inc., 636 E Saint Charles Street, Star Route 3, San Andreas, CA 95249. Tel: +1 209 754 5802. www.davebean.com.
- Elgin Industries, Inc., 1100 Jansen Farm Drive, Elgin, IL 60123, USA. Tel: +1 800 323 6764. www.elginind.com.
- Kent Performance Cams, Ltd., Units 1-7

Military Road, Shomcliffe Industrial Estate,
Folkstone, Kent, CT20 3UJ, UK. Tel: + 44 (0)
1303 248666. www.kentcams.com.

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- J. Lamont and T. Andresen, *How to Build and Maintain Competitive (yet legal) Formula Ford 1600 Engines* (1999).

Recondition a Weber 32DFM Twin Choke Downdraught Carburetor

As used in the Seven the 1600 cc engine was essentially that from the Ford Cortina GT and used a standard Ford intake manifold with a single Weber 32DFM twin choke downdraught carburetor. The original downdraft Weber 32DFM twin choke downdraught carburetor had melted during the fire ([\[link\]](#)) and become fused to the intake manifold ([\[link\]](#)).

The remains of the Weber 32DFM twin choke downdraught carburetor and the intake manifold in place on the engine.



The melted Weber 32DFM twin choke downdraught carburetor fused to the intake manifold showing the damage to the latter at cylinder 2 and 3 ports in

particular.



As a replacement it is still possible to purchase new Weber carburetors (Southern Carburettors or Weber Carbs Direct), however, the 1969 Lotus Seven S3 that I had been previously restored then used on the Millennium Monte in 2000 and the Winter

Challenge in 2001 ([\[link\]](#)), had been converted to a race car with twin side draft Weber 40 DCOE carburetors ([\[link\]](#)). Therefore, it was decided to recondition the old unused Weber 32DFM carburetor ([\[link\]](#)).

The 1969 Lotus Seven S3 while on the 2001 Winter Challenge.



The 1969 Lotus Seven S3 racing at Sebring after converting to twin Weber DCOEs. Copyright by SVRA (2009).



View of the replacement Weber 32DFM carburetor.



Even though the carburetor had been working up to the point it was removed, it had not been used in 12 years. It was decided therefore to replace all the gaskets and clean all the jets, etc. The rebuild kit for

Weber 32/36 DGV/DFM carburetors is available from Pegasus Auto Racing Supplies (Part No. 1586-18).

The first step was to remove the Formula Ford style carburetor spacer with gaskets ([\[link\]](#)). Both new replacement and the standard carburetor-to-manifold gasket (0.063" thick) are available from Pegasus Auto Racing Supplies. The final decision may rest with the clearance of the air filter with the bonnet.

The typical carburetor spacer with gaskets as used for downdraft Weber 32DFM carburetors in Formula Ford applications.



Removal of the air filter housing is accomplished by first undoing the retaining nuts for the top cover ([\[link\]](#)), followed by removal of the air filter cover

([link](#)). With the cover of the filter housing removed, the filter is lifted out exposing the four bolts that hold the bottom plate of the air filter housing to the carburetor ([link](#)). Undoing these bolts allows for removal of the bottom plate of the air filter housing from the carburetor ([link](#)). Underneath is a card gasket, which is lifted of ([link](#)) and labeled for reuse ([link](#)). View of the air filter cover after the retaining nuts are removed.



View of the air filter and chokes after removal of the air filter cover showing the threaded pins that fit through the holes in the cover.



View after removal of the air filter showing two of the four bolts that hold the bottom plate of the air filter housing.



View after removal of the bottom plate of the air filter housing.



View of the top of the Weber 32DFM carburetor after removal of the air filter housing.



The card gasket which fits between the carburetor and the air filter housing (see [\[link\]](#)).

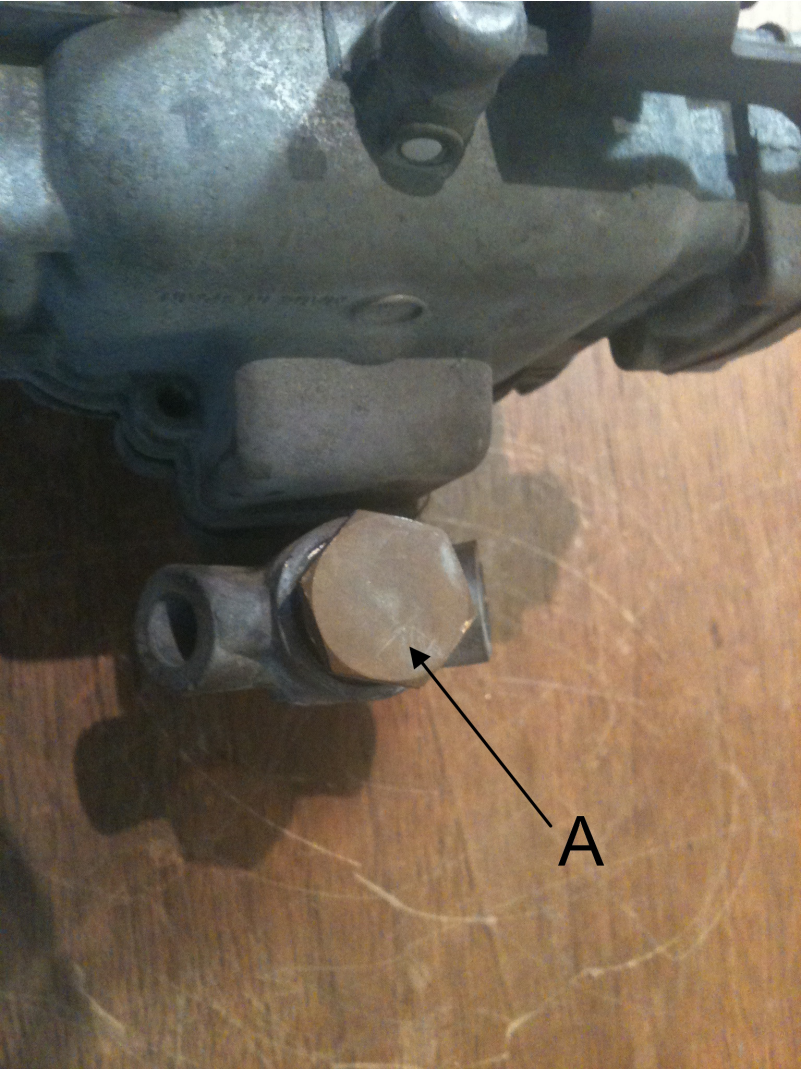


Once the air filter housing is removed, the various components of the carburetor can be cleaned and/or replaced. The fuel inlet was unscrewed ([\[link\]](#)) to allow for air to be blown through. Turning the carburetor upside-down allows access to the strainer (fuel filter) inspection plug ([\[link\]](#)), which is unscrewed to reveal the strainer assembly ([\[link\]](#)). The strainer assembly (filter) is carefully removed by hand or using tweezers and replaced with a new assembly that is included in the rebuild kit ([\[link\]](#)). The fuel channels are blown out with air prior to inserting the new strainer assembly and refitting the inspection plug.

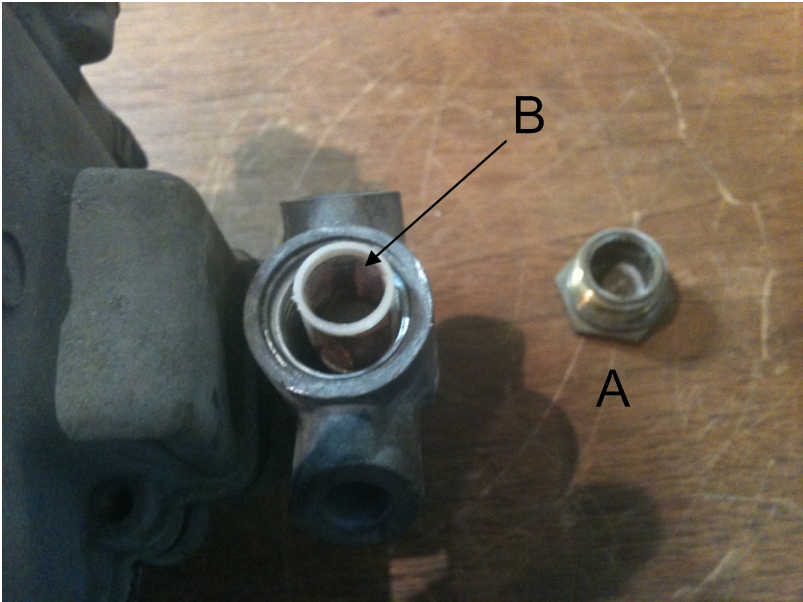
Removal of the fuel inlet.



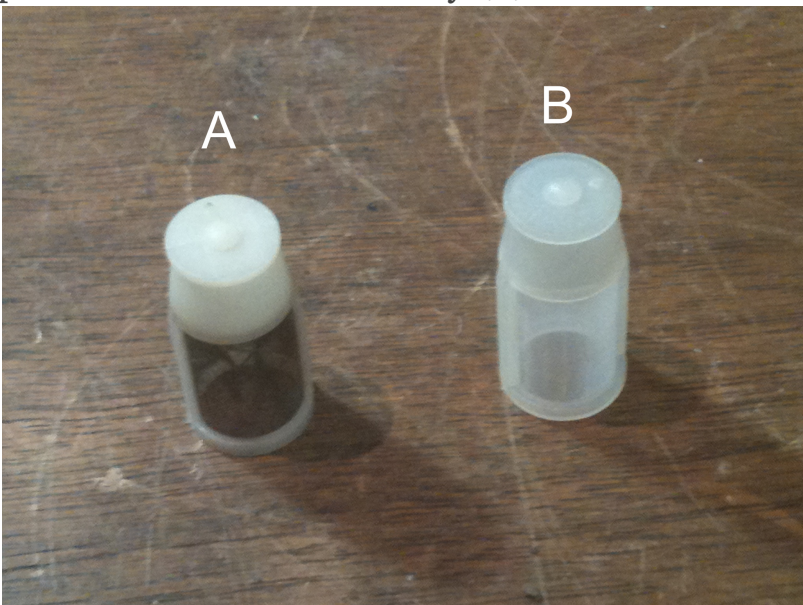
A view of the strainer inspection plug (A).



View after removal of the strainer inspection plug (A) showing the cylindrical strainer assembly (B).



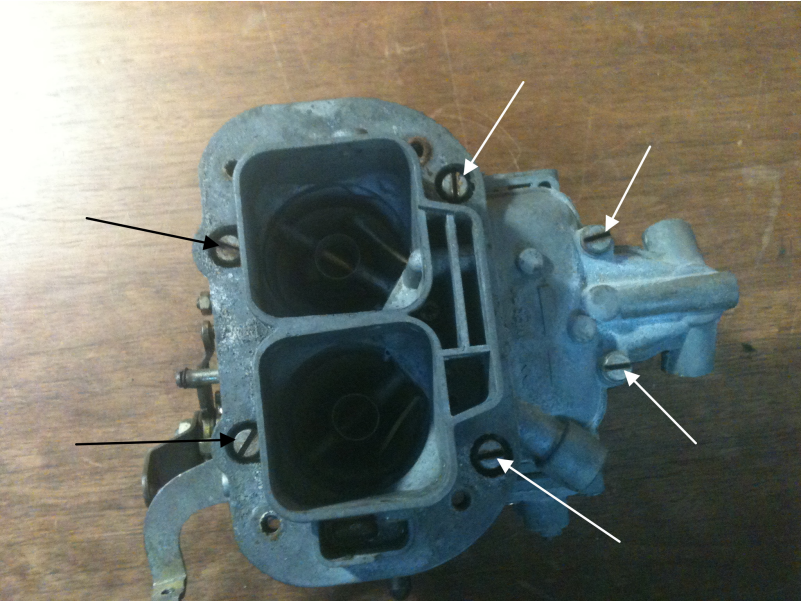
View of the old strainer assembly (A) and a new replacement strainer assembly (B).



The top of the carburetor is removed by removing six ([link](#)) cover fixing screws with a flat head

screwdriver ([\[link\]](#)). This allows access to the float assembly and jets. Taking the cover of the carburetor first, the cover gasket is removed. The cover is then turned upside down so the float assembly is on top ([\[link\]](#)). The float fixing pin that holds the float assembly in place is removed by pushing from one side ([\[link\]](#)A). Once the float assembly is free, the needle of the needle valve can be unhooked ([\[link\]](#) and [\[link\]](#)). Using a 10 mm wrench or socket undo the needle valve seating and remove the gasket below. Replacement seating and gasket are provided in the rebuild kit ([\[link\]](#)). The new gasket is fitted along with the new needle valve seating. The hook on the new needle valve is hooked onto the float, and the float assembly positioned into the carburetor cover. The fulcrum pin is inserted into the two posts to hold the float assembly in place. It is always worth checking that the height of the floats has not changed during this procedure.

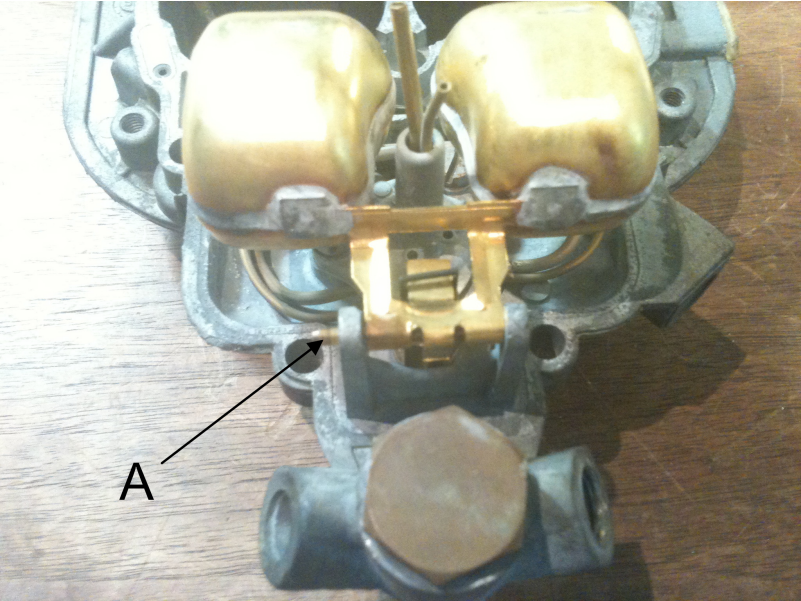
View of top of the carburetor showing the six cover fixing screws (arrowed).



Unscrewing one of the cover fixing screws that hold the carburetor cover in place.



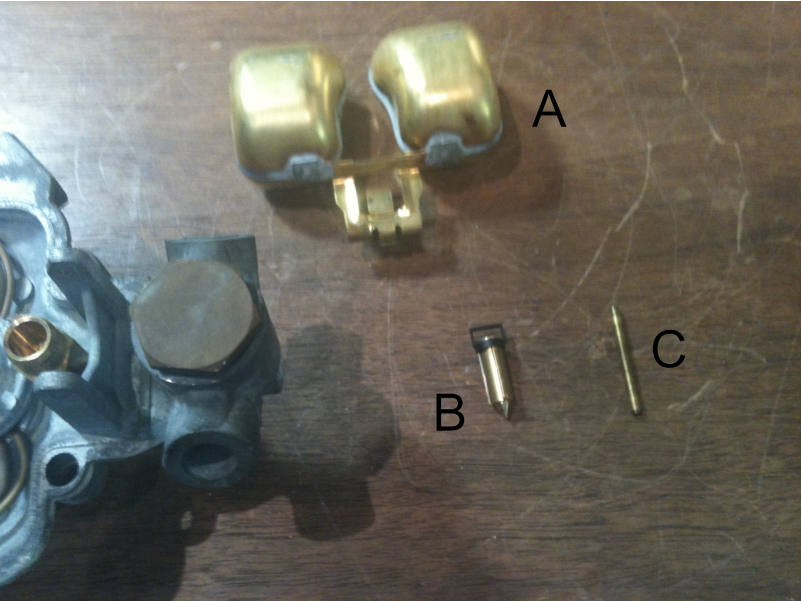
View of the inside of the top of the carburetor showing the float assembly and the fixing (fulcrum) pin partially removed (A).



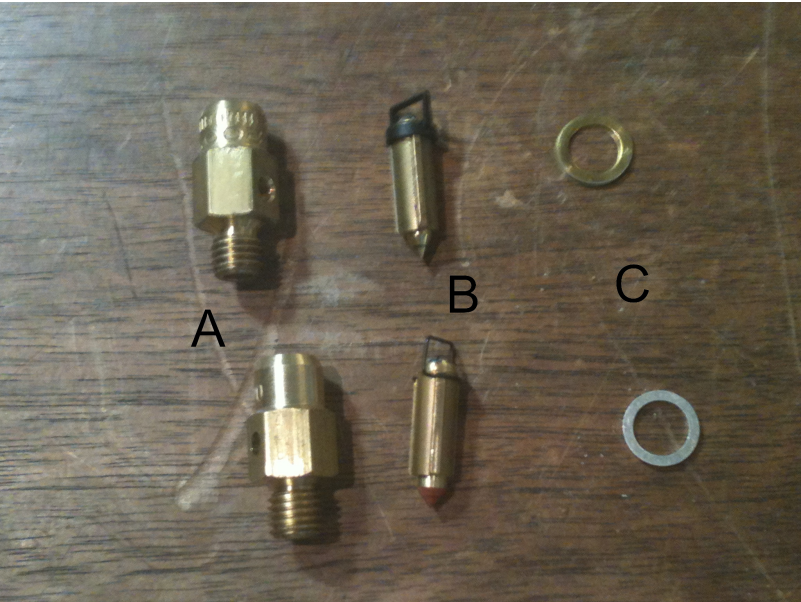
Side view of the float assembly showing the needle of the needle valve.



The original float assembly (A), needle valve (B), and float assembly fixing pin (C).



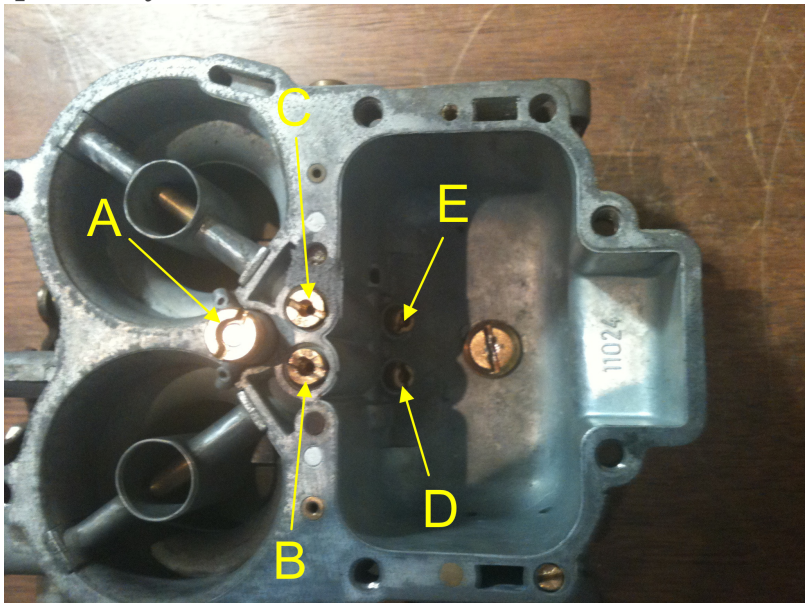
The original (upper) and replacement (lower) needle valve seating (A), needle valve (B), and needle valve gasket (C).



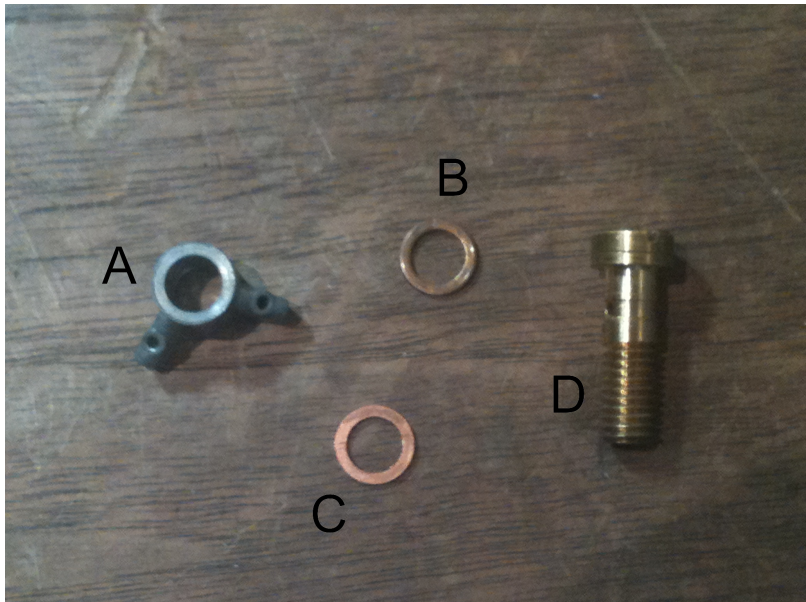
Before the carburetor cover is reattached to the

body, each the main and air corrector jets ([\[link\]](#)) were removed and cleaned with break fluid and compressed air. In addition, the accelerator pump ([\[link\]](#)A) is removed by unscrewing the pump delivery valve ([\[link\]](#)D). The old gaskets are replaced by new ones from the rebuild kit ([\[link\]](#)B and C). The accelerator pump is reattached and screwed in place.

Inside of the Weber 32DFM carburetor showing the accelerator pump (A), the primary and secondary air corrector jets (B and C, respectively), and the primary and secondary main jets (D and E, respectively).



View of the accelerator valve (A), the old pump jet gasket (B), the new pump jet gasket (C) and the pump delivery valve assembly (D).



The accelerator pump cover is removed by undoing the four screws that hold it in place ([\[link\]](#)). With the cover of the accelerator pump diaphragm assembly will fall out along with the pump loading spring ([\[link\]](#)). The spring is refitted into the cup in the body of the carburetor ([\[link\]](#)). The new accelerator pump diaphragm assembly ([\[link\]](#)B) is held in the cover assembly and the whole unit reattached, and screwed in place ([\[link\]](#)). View of the accelerator pump cover assembly after removing the four cover fixing screws.



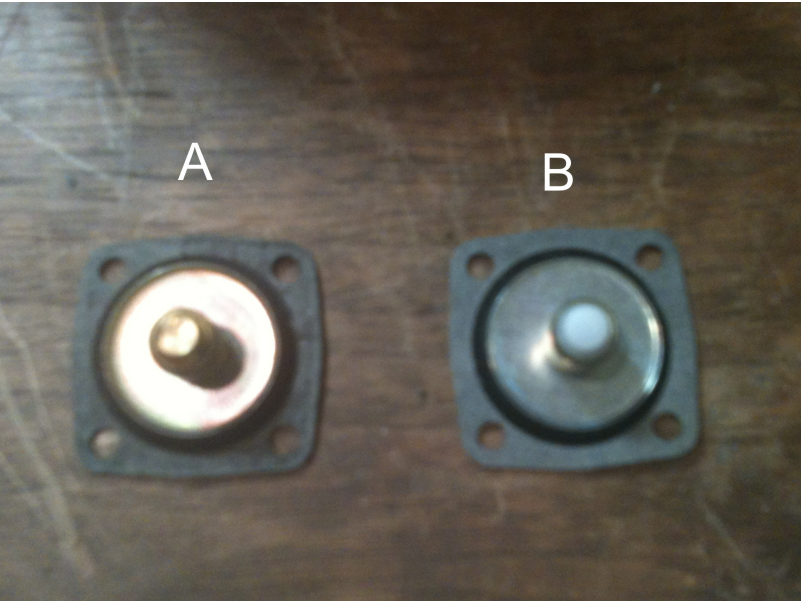
View of the accelerator pump housing after removal of the accelerator pump diaphragm assembly and the pump loading spring.



View of the accelerator pump housing and the pump loading spring.



The old accelerator pump diaphragm assembly (A) and the new accelerator pump diaphragm assembly (B).

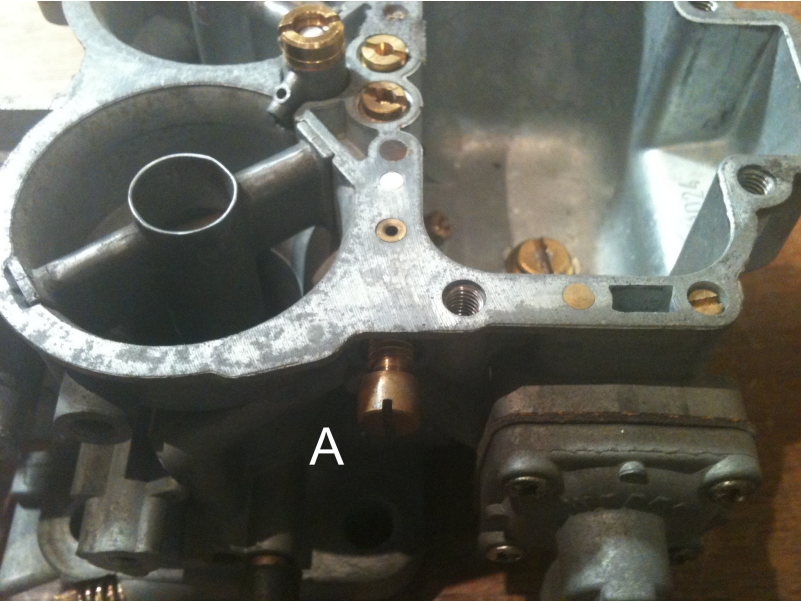


View of the replaced accelerator pump cover assembly.



The idling jet holder on the same side of the carburetor body as the accelerator pump ([\[link\]](#)) is unscrewed and the primary idle jet removed and cleaned ([\[link\]](#)) before replacing back into the carburetor body with a new washer. This process is repeated for the secondary idling jet on the other side of the carburetor.

View of the idling jet holder (A).



Idling jet in its holder with a new gasket. The old gasket is shown beside.



The cover gasket is replaced on the cover of the carburetor ensuring that the floats are not hindered

from movement. The cover is then carefully replaced and the cover fixing screws. The air filter housing is replaced along with the fuel inlet. The filter will be replaced with a new unit once the clearance with the bonnet is checked upon instillation.

Resources

- Southern Carburetters, Unit 7 Priestley Way, Crawley, West Sussex. RH10 9NT, UK. Tel: +44 (0) 1293 533843. www.sciperformance.co.uk.
- Pegasus Auto Racing Supplies, 2475 S 179th Street, New Berlin WI 53146, USA. Tel: +1 262 317 1234. www.pegasusautoracing.com.
- Weber Carbs Direct, 20 Constance Court, Hauppauge, NY 11788, USA. Tel: +1 866 679 3237. www.webercarbsdirect.com.

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- A. K. Legg, D. Peers, R. Maddox, and J. Haynes, *The Haynes Weber Carburetor Manual*, Haynes Publishing Group, Sparkford, UK (1995).

Restoration of the Fuel Tank

The Lotus Seven S4 (Type 60) was fitted with a 7½ gallons (34 L, 9 gal US) steel petrol tank. It is held in place by two bolts (which run through holes in flanges at the lower lip of the ends of the tank) and by two bolts that are also used for mounting the body. The tank shows some fire damage with removal of paint towards the cockpit side (see [\[link\]](#)). In addition, the fuel gauge sender unit has been subjected to sufficient heat to melt the connectors ([\[link\]](#)).

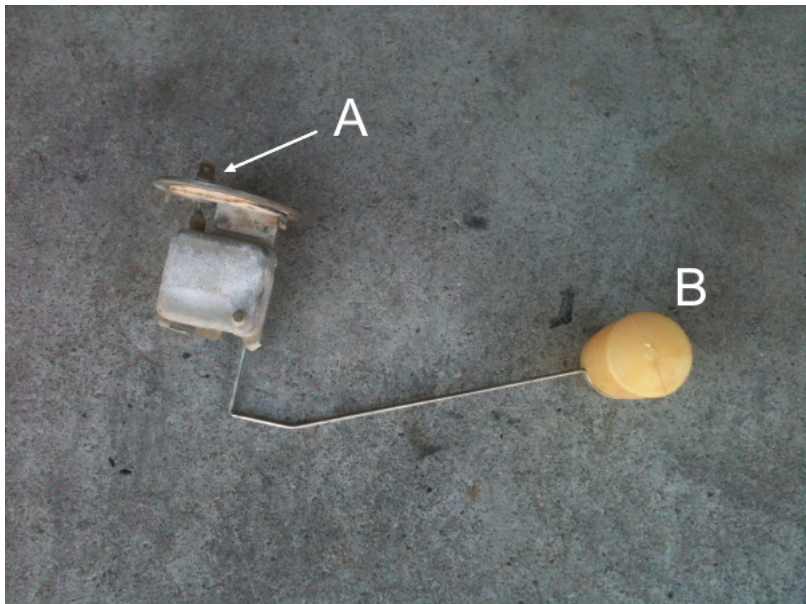
The fuel tank after removal from the chassis.



The remains of the fuel gauge sender unit on the top of the fuel tank.



The fuel gauge sender was removed in order to ascertain potential damage. Upon inspection, it was decided to replace the mechanicals, connectors, and the float, in order to simplify refitting, because the replacement sender required a different mounting bracket. Replacement fuel tank sender units are available for Smiths gauges from APT Instruments (Bloomington, MN). [\[link\]](#) shows the rebuilt sender unit. The tank was then restored and rebuilt by Lucas Racing and Restoration (Houston, TX). Rebuilt fuel gauge sender unit showing the external electrical connector (A) and the new plastic float (B).



Once the sender was removed, along with the old rubber hoses, the outside of the tank was media blasted to remove all the paint and reveal any defects ([\[link\]](#) and [\[link\]](#)). Of which none were apparent, and thus the decision was made to reuse the tank.

The fuel tank after removal of the hoses and fuel sender and media blasting, should be compared to the original condition shown in [\[link\]](#).



A view of the fuel sender location and the fuel pick-up connector (A).



After thorough cleaning the tank was dried and then painted with black enamel. Refitting the rebuilt

sender ([\[link\]](#)) and hoses ([\[link\]](#) and [\[link\]](#)). The fuel tank after painting, and refitting the fuel sender and fitting new hoses. This should be compared to the original condition shown in [\[link\]](#) and after media blasting ([\[link\]](#)).



Close-up view of the fuel sender refitted into the tank.



Close-up view of the new fuel inlet hose.



Resources

- Lucas Racing and Restoration, 10030 Talley Lane, Houston, Texas 77041, USA. Tel: +1 713 462 0068. www.lucasracinginc.com.
- Gaugeguys dba APT Instruments, 9632 Humboldt Ave S, Bloomington, MN 55431, USA. Tel: +1 952 881 7095. www.gaugeguys.com.

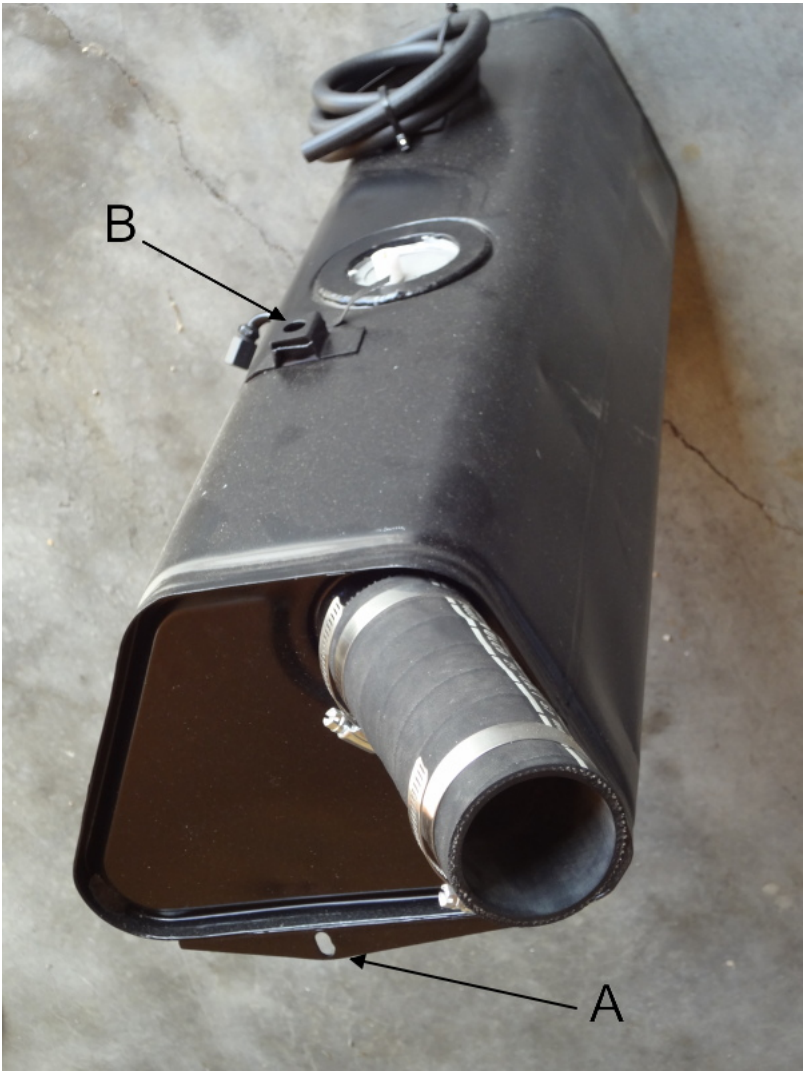
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Installation of the Fuel Tank

The fuel tank on the Series 4 Lotus Seven is located above the rear axle, and as such must be installed prior to the axle and rear suspension components. Unfortunately, the tank cannot be finally located until the body is attached. This is because the main fixing bolts also double (more correctly *triple*) as the seat harness shoulder attachment (inner side for both driver and passenger) and the attachment of the body to the chassis. Therefore, during fitting temporary bolts are used to align the top of the tank. These bolts pass into captive nuts in the top of the tank ([\[link\]](#)B). The tank is also held in place by brackets at the lower ends of the tank ([\[link\]](#)A) where a nut and bolt (each side) attach it to the sides of the chassis.

The restored fuel tank showing the attachment points to (A) the chassis side rail and (B) the upper body/chassis mounting.



The tank is held in place with two bolts that are temporarily used to attach the tank to the chassis via the captive nuts ([\[link\]](#)A). These will be removed and replaced once the body is fitted; however, they are useful in allowing the tank to be aligned while the side bolts are tightened in place ([\[link\]](#)). It is worth noting that the fuel sender unit

is clear of the chassis allowing for the connection of the wiring ([\[link\]](#)B). The installed fuel tank is shown in [\[link\]](#).

View of the top of the fitted fuel tank showing the temporary placement of the bolt that will eventually hold the body to the chassis (A), and the fuel sender unit (B).



View of the bottom of the fuel tank showing the attachment to the chassis.



Fuel tank fitted to the chassis.



Ceramic Coating the Exhaust System

The exhaust system of the Type 60 Series 4 Lotus Seven consists of two 2-into-1 manifolds ([\[link\]](#) and [\[link\]](#)) that join outside the chassis to a 2-into-1 collector that is part of the side pipe ([\[link\]](#)). The silencer (muffler) is positioned transversely under the boot of the car ([\[link\]](#)). The silencer had been replaced at some point by a glass pack “Cherry Bomb” brand unit, as evidence from the color. It was decided to retain this despite its expected louder sound.

The two 2-into-1 exhaust manifolds in place during the teardown.



The two 2-into-1 exhaust manifolds after removal.



Left hand side of the rolling chassis, during teardown, showing the 2-into-1 collector and side pipe.



Right hand side of the rolling chassis during

teardown showing the position of the silencer (muffler).



Each of the components was cleaned and ceramic coated by PolyDyne Performance Coatings to provide corrosion protection ([\[link\]](#) – [\[link\]](#)). The outer (cylinders 1 and 4) 2-into-1 exhaust manifold after coating. Compare to [\[link\]](#).



The central (cylinders 2 and 3) 2-into-1 exhaust manifold after coating. Compare to [\[link\]](#).



The coated 2-into-1 collector and side pipe that runs along the outside of the chassis.



The coated silencer (muffler) and associated pipes.



The entire exhaust system after coating.



Resources

- PolyDyne Performance Coatings, 11211 Neeshaw Drive, Houston, Texas 77065, USA. Tel: +1 888 765 9396 or +1 281 894 6382.

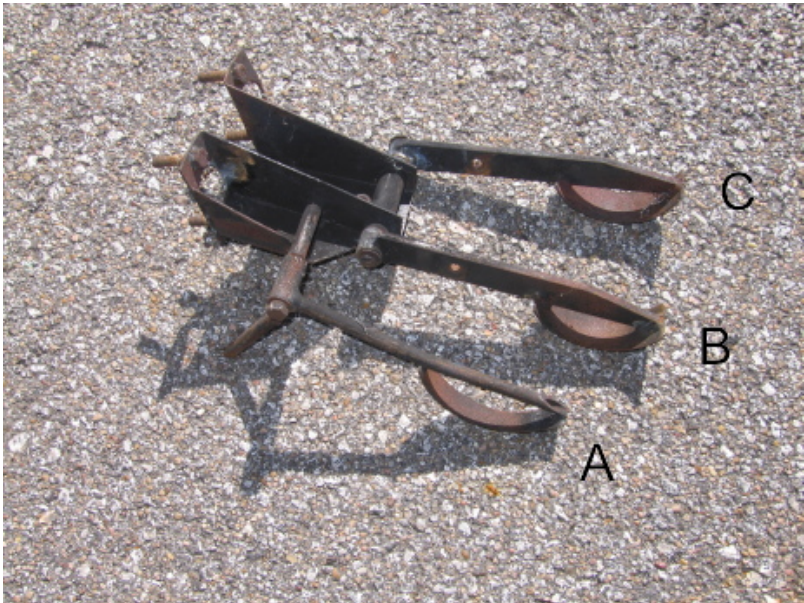
www.polydyn.com.

- Cherry Bomb, 2400 Maremont Parkway,
Loudon, TN 37774. Tel: +1 866 869 9704.
www.cherrybomb.com.

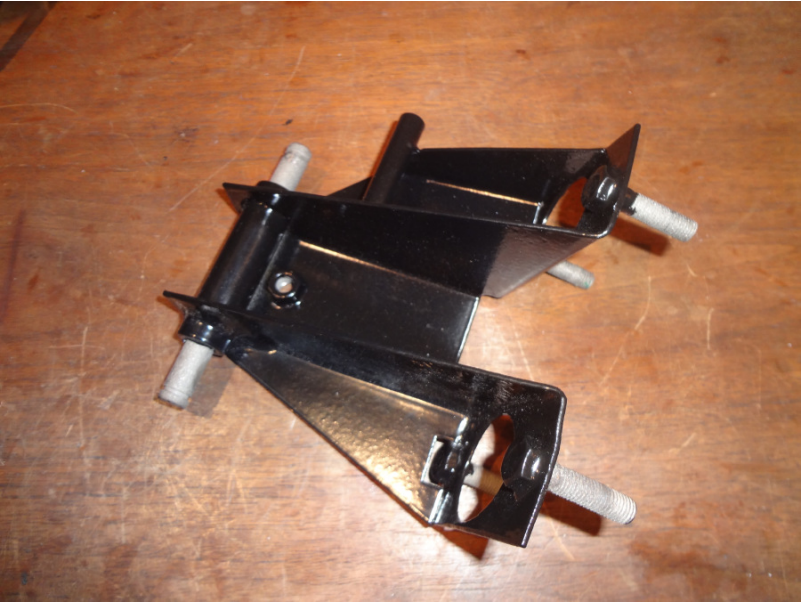
Restoration of the Pedal Unit

The pedal unit was complete but badly corroded ([\[link\]](#)). It was decided to disassemble the unit, clean and powder coat all the components. After media blasting the individual components were powder coated by Custom Coatings. [\[link\]](#) and [\[link\]](#) show the various components after powder coating.

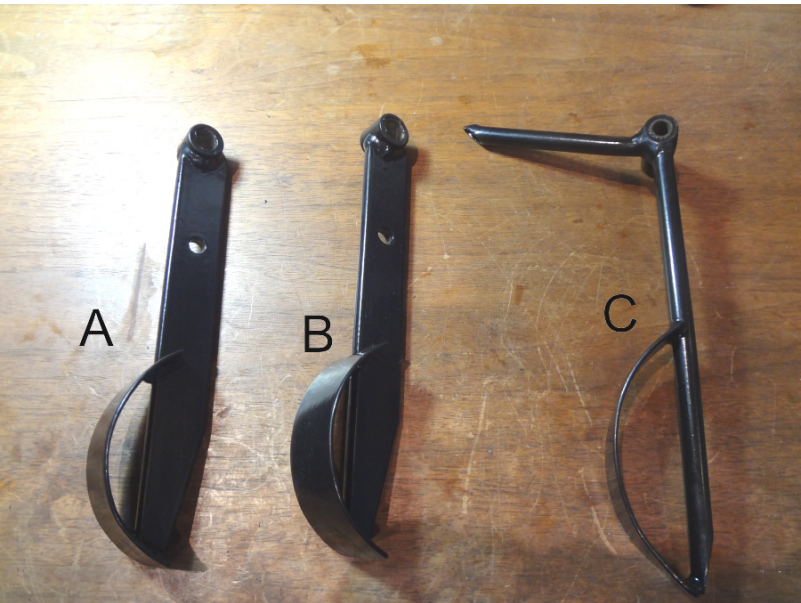
The pedal unit: throttle (A), brake (B), and clutch (C).



Cleaned and powder coated pedal bracket.

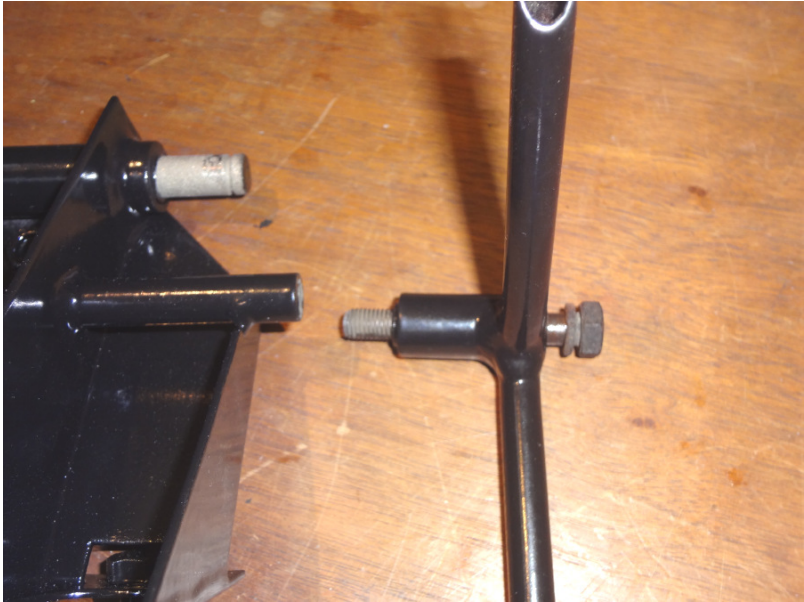


Cleaned and powder coated pedals: clutch (A), brake (B), and throttle (C).

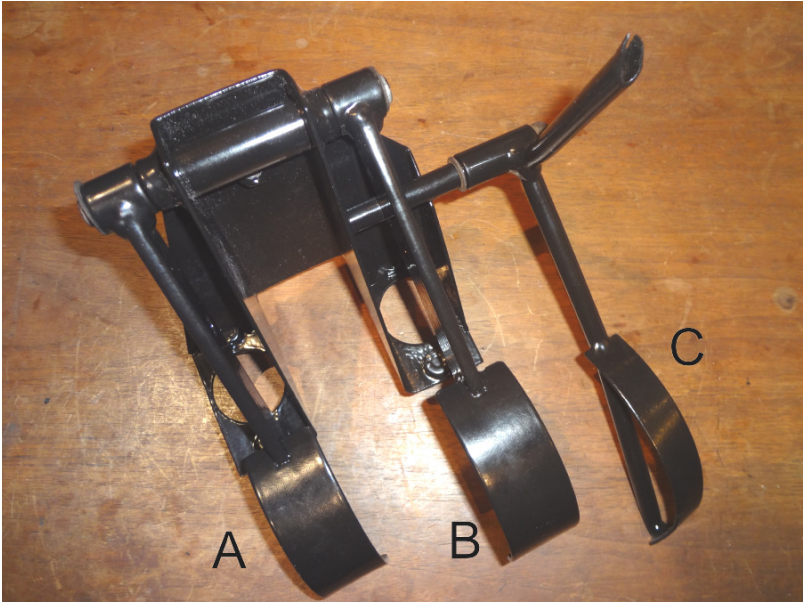


Since the clutch and brake pedals rotate on the shafts of the pedal unit it is important to mask not

only the shafts on the bracket (see [\[link\]](#)), but also inside of the pivot holes in the pedals (see [\[link\]](#)). In a similar manner, the throttle pedal pivots on a bolt (see [\[link\]](#)); the inside of the pivot hole must be masked during powder coating. The final assembled pedal unit is shown in [\[link\]](#).
Attachment of the throttle pedal.



View of the reassembled powder coated pedal unit: clutch (A), brake (B), and throttle (C).



Resources

- Custom Coatings, 16219 Dundee, Cypress, TX 77429, USA. Tel: +1 281 813 0119.

Restoration of the Radiator Grill

Introduction

Magnetic materials attract the attention of researchers and engineers because of their potential for application in magnetic and electronic devices such as navigational equipment, computers, and even high-speed transportation. Perhaps more valuable still, however, is the insight they provide into fundamental physicals. Magnetic materials provide an opportunity for studying exotic quantum mechanical phenomena such as quantum criticality, superconductivity, and heavy fermionic behavior intrinsic to these materials. A battery of characterization techniques exist for measuring the physical properties of these materials, among them a method for measuring the specific heat of a material throughout a large range of temperatures. Specific heat measurements are an important means of determining the transition temperature of magnetic materials—the temperature below which magnetic ordering occurs. Additionally, the functionality of specific heat with temperature is characteristic of the behavior of electrons within the material and can be used to classify materials into different categories.

Temperature-dependence of specific heat

The molar specific heat of a material is defined as the amount of energy required to raise the temperature of 1 mole of the material by 1 K. This value is calculated theoretically by taking the partial derivative of the internal energy with respect to temperature. This value is not a constant, as it is typically treated in high-school science courses: it depends on the temperature of the material.

Moreover, the temperature-dependence itself also changes based on the type of material. There are three broad families of solid state materials defined by their specific heat behaviors. Each of these families is discussed in the following sections.

Insulators

Insulators have specific heat with the simplest dependence on temperature. According to the Debye theory of specific heat, which models materials as phonons (lattice vibrational modes) in a potential well, the internal energy of an insulating system is given by [\[link\]](#), where T_D is the Debye temperature, defined as the temperature associated with the energy of the highest allowed phonon mode of the material. In the limit that $T \ll T_D$, the energy expression reduces to [\[link\]](#).

$$U = 9 N k_B T^4 T_D^3 \int_0^{T_D/T} \frac{x^3 e^x - 1}{x^4} dx$$

$$U = \frac{3 \pi^4}{5} N k_B T^4 \left(\frac{T}{T_D} \right)^3$$

For most magnetic materials, the Debye temperature is several orders of magnitude higher than the temperature at which magnetic ordering occurs, making this a valid approximation of the internal energy. The specific heat derived from this expression is given by [\[link\]](#).

$$C_v = \partial U / \partial T = 12 \pi^4 N k_B^5 T^3 / (5 D^3 T^3) = \beta T^3$$

The behavior described by the Debye theory accurately matches experimental measurements of specific heat for insulators at low temperatures. Normal insulators, then, have a T^3 dependence in the specific heat that is dominated by contributions from phonon excitations. Essentially all energy absorbed by insulating materials is stored in the vibrational modes of a solid lattice. At very low temperatures this contribution is very small, and insulators display a high sensitivity to changes in heat energy.

Metals: Fermi liquids

While the Debye theory of specific heat accurately describes the behavior of insulators, it does not adequately describe the temperature dependence of the specific heat for metallic materials at low temperatures, where contributions from delocalized conduction electrons becomes significant. The predictions made by the Debye model are corrected in the Einstein-Debye model of specific heat, where an additional term describing the contributions from

the electrons (as modeled by a free electron gas) is added to the phonon contribution. The internal energy of a free electron gas is given by [\[link\]](#), where $g(E_f)$ is the density of states at the Fermi level, which is material dependent. The partial derivative of this expression with respect to temperature yields the specific heat of the electron gas, [\[link\]](#).

$$U = \pi^2 \frac{6}{5} (k_B T)^2 g(E_f) + U_0$$

$$C_v = \pi^2 \frac{3}{2} k_B^2 g(E_f) T = \gamma T$$

Combining this expression with the phonon contribution to specific heat gives the expression predicted by the Einstein-Debye model, [\[link\]](#).

$$C_v = \pi^2 \frac{3}{2} k_B^2 g(E_f) T + 12 \pi^4 \frac{N}{5} \frac{k_B^4}{T^3} D^3$$

$$T^3 = \gamma T + \beta T^3$$

This is the general expression for the specific heat of a Fermi liquid—a variation on the Fermi gas in which fermions (typically electrons) are allowed to interact with each other and form quasiparticles—weakly bound and often short-lived composites of more fundamental particles such as electron-hole pairs or the Cooper pairs of BCS superconductor theory.

Most metallic materials follow this behavior and are thus classified as Fermi liquids. This is easily confirmed by measuring the heat capacity as a function of temperature and linearizing the results by plotting C/T vs. T^2 . The slope of this graph equal

the coefficient β , and the y-intercept is equal to γ . The ability to obtain these coefficients is important for gaining understanding of some unique physical phenomena. For example, the compound YbRh_2Si_2 is a heavy fermionic material—a material with charge carriers that have an “effective” mass much greater than the normal mass of an electron. The increased mass is due to coupling of magnetic moments between conduction electrons and localized magnetic ions. The coefficient γ is related to the density of states at the Fermi level, which is dependent on the carrier mass. Determination of this coefficient via specific heat measurements provides a way to determine the effective carrier mass and the coupling strength of the quasiparticles.

Additionally, knowledge of Fermi-liquid behavior provides insight for application development. The temperature dependence of the specific heat shows that the phonon contribution dominates at higher temperatures, where the behavior of metals and insulators is very similar. At low temperatures, the electronic term is dominant, and metals can absorb more heat without a significant change in temperature. As will be discussed briefly later, this property of metals is utilized in low-temperature refrigeration systems for heat storage at low temperatures.

Metals: non-Fermi liquids

While most metals fall under the category of Fermi liquids, there are some that show a different dependence on temperature. Naturally, these are classified as *non-Fermi* liquids. Often, deviation from Fermi-liquid behavior is an indicator of some of the interesting physical phenomena that currently garner the attention of many condensed matter researchers. For instance, non-Fermi liquid behavior has been observed near quantum critical points. Classically, fluctuations in physical properties such as magnetic susceptibility and resistivity occur near critical points which include phase changes or magnetic ordering transitions. Normally, these fluctuations are suppressed at low temperatures—at absolute zero, classical systems collapse into the lowest energy state and remain stable; However, when the critical transition temperature is lowered by the application of pressure, doping, or magnetic field to absolute zero, the fluctuations are *enhanced* as the temperature approaches absolute zero, propagating throughout the whole of the material. As this is not classically allowed, this behavior indicates a quantum mechanical effect at play that is currently not well understood. The transition point is then called a quantum critical point. Non-Fermi liquid behavior as identified by deviations in the expected specific heat, then, is used to identify materials that can provide an experimental basis for development of a theory that describes the physics of quantum criticality.

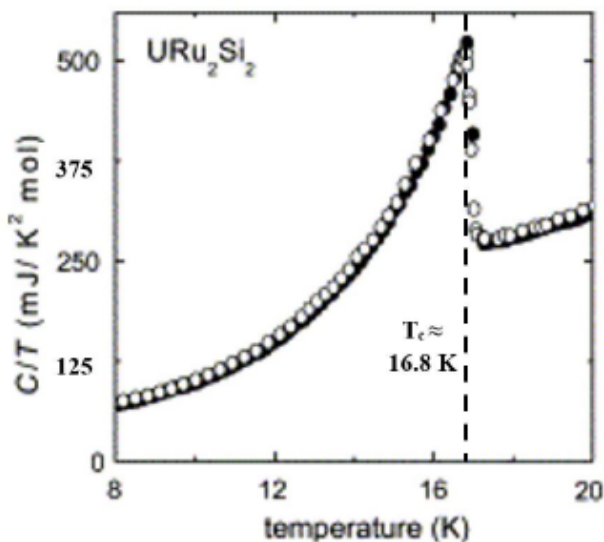
A Schottky anomaly at the magnetic ordering

temperature of URu₂Si₂ . Adapted with permission from J. C. Lashley, M. F. Hundley, A. Migliori, J. L. Sarrao, P. G. Pagliuso, T. W. Darling, M. Jaime, J. C. Cooley, W. L. Hults, L. Morales, D. J. Thoma, J. L. Smith, J. Boerio-Goates, B. F. Woodfield, G. R. Stewart, R. A. Fisher, and N. E. Phillips. *Cryogenics*, 2003, **43**, 369. Copyright: Elsevier publishing.

Determination of magnetic transition temperatures via specific heat measurements

While analysis of the temperature dependence of specific heat is a vital tool for studying the strange physical behaviors of quantum mechanics in solid state materials, these are studied by only a small subsection of the physics community. The utility of specific heat measurements is not limited to a few niche subjects, however. Possibly the most important use for specific heat measurements is the determination of critical transition temperatures. For any sort of physical state transition—phase transitions, magnetic ordering, transitions to superconducting states—a sharp increase in the specific heat occurs during the transition. This increase in specific heat is the reason why, for example, water does not change temperature as it changes from a liquid to a solid. These increases are quite obvious in plots of the specific heat vs.

temperature as seen in [\[link\]](#). These transition-associated peaks are called Schottky anomalies, as normal specific heat behavior is not followed near to the transition temperature.



For the purposes of this chapter, the following sections will focus on specific heat measurements as they relate to magnetic ordering transitions. The following sections will describe the practical aspects of measuring the specific heat of these materials. A schematic representation depicting the thermal connection between the sample and the heat reservoir. The low-temperature heat-pulse temperature decay for a copper standard. Reused with permission from J. S. Hwang, K. J. Lin, and C. Tien. *Rev. Sci. Instrum.*, 1997, **68**, 94. Copyright: AIP publishing. A thermal relaxation decay graph for a

sample of a Pb sample displaying the two- τ effect. Reused with permission from J. S. Hwang, K. J. Lin, and C. Tien. *Rev. Sci. Instrum.*, 1997, **68**, 94.

Copyright: AIP publishing. A schematic representation of a Gifford-McMahon type pulse tube cooler. Adapted from P. D. Nissen. *Closed Cycle Refrigerators – Pulse Tube Coolers*. Retrieved from <www.nbi.dk/~nygard/DPN-Pulsetubecoolers_low2010.pdf>.

Temperature cycle of a gas element moving in the pulse tube cooler. **A to B:** Gas initially at T_H moves through the regenerator to heat exchanger X2 dropping to T_L . **B to C:** Gas is compressed and the temperature rises above T_H . **C to D:** Gas is shunted along to X3 and drops to T_H . **D to E:** Gas is expanded adiabatically to $T < T_L$. **E to F:** Cold gas is shunted to X2 and rises to T_L , absorbing heat from the sample. **F to G:** Gas at T_L moves through the regenerator reabsorbing heat until it reaches T_H at heat exchanger X1. The sample platform with important components of the sample temperature control system. Reused with permission from R. J. Schutz. *Rev. Sci. Instrum.*, 1974, **45**, 548. Copyright: AIP publishing.

A practical guide to low-temperature specific heat measurements

The thermal relaxation method of measurement

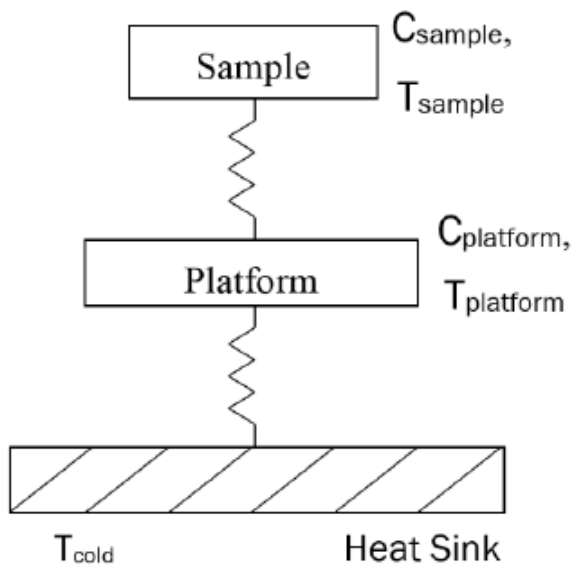
Specific heat is measured using a calorimeter. The

design of basic calorimeters for use over a short range of temperatures is relatively simple. They consist of a sample with a known mass and an unknown specific heat, an energy source which provides heat energy to the sample, a heat reservoir (of known mass and specific heat) that absorbs heat from the sample, insulation to provide adiabatic conditions inside the calorimeter, and probes for measuring the temperature of the sample and the reservoir. The sample is heated with a pulse to a temperature higher than the heat reservoir, which decreases as energy is absorbed by the reservoir until a thermal equilibrium is established. The total energy change is calculated using the specific heat and temperature change of the reservoir. The specific heat of the sample is calculated by dividing the total energy change by the product of the mass of the sample and the temperature change of the sample.

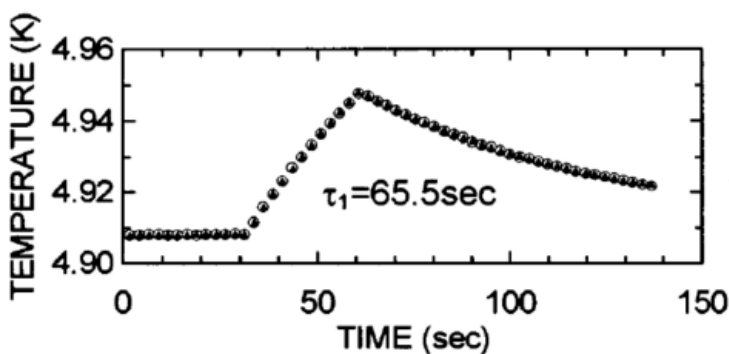
However, this method of measurement produces an average value of the specific heat over the range of the change in temperature of the sample, and therefore, is insufficient for producing accurate measurements of the specific heat as a function of temperature. The solution, then, is to minimize the temperature change by reducing the amount of heat added to the system; yet, this presents another obstacle to making measurement as, in general, the temperature change of the reservoir is much smaller than that of the sample. If the change in

temperature of the sample is minimized, the temperature change of reservoir becomes too small to measure with precision. A more direct method of measurement, then, seems to be required.

Fortunately, such a method exists: it is known as the thermal relaxation method. This method involves measurement of the specific heat without the need for precise knowledge of temperature changes in the reservoir. In this method, solid samples are affixed to a platform. Both the specific heat of the sample and the platform itself contribute to the measured specific heat; therefore, the contribution from the platform must be subtracted. This contribution is determined by measuring the specific heat without a sample present. Both the sample and the platform are in thermal contact with a heat reservoir at low temperature as depicted in [\[link\]](#).



A heat pulse is delivered to the sample to produce a minimal increase in the temperature of the sample. The temperature is measured vs. time as it decays back to the temperature of the reservoir as shown in [\[link\]](#).

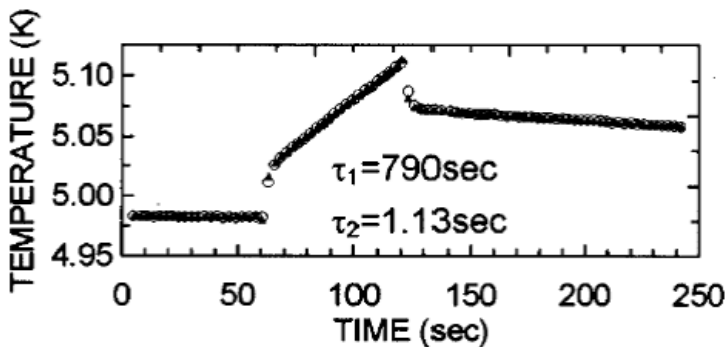


The temperature of the sample decays according to [\[link\]](#), where T_0 is the temperature of the heat

reservoir, and ΔT is the temperature difference between the initial sample temperature and the reservoir temperature. The decay time constant τ is directly related to the specific heat of the sample by [\[link\]](#), Where K is the thermal conductance of the thermal link between the sample and the heat reservoir. In order for this to be valid, however, the thermal conductance must be sufficiently large that the energy transfer from the heated sample to the reservoir can be treated as a single process. If the thermal conduction is poor, a two- τ behavior arises corresponding to two separate processes with different time constants—slow heat transfer from the sample to the platform, and fast transfer from the platform to the reservoir. [\[link\]](#) shows a relaxation curve in which the two- τ behavior plays a significant role.

$$T = \Delta T e^{-t/\tau} + T_0$$

$$\tau = C_p / K$$



The two- τ effect is generally undesirable for making measurements. It can be avoided by reducing thermal conductance between the sample

and the platform, effectively making the contribution from the heat transfer from the sample to the platform insignificant compared to the transfer from the platform to the reservoir; however, if the conductance between the sample and the platform is too low, the time required to reach thermal equilibrium becomes excessively long, translating into very long measurement times. It is necessary, then, to optimize the conductance to compensate for both of these issues. This essentially provides a limitation on the temperature range over which these effects are insignificant.

In order to measure at different temperatures, the temperature of the heat reservoir is increased stepwise from the lowest temperature until the desired temperature range is covered. At each step, the temperature is allowed to equilibrate, and a data point is measured.

Instrumentation

Thermal relaxation calorimeters use advanced technology to make precise measurements of the specific heat using components made of highly specialized materials. For example, the sample platform is made of synthetic sapphire which is used as a standard material, the grease which is applied to the sample to provide even thermal contact with the platform is a special hydrocarbon-based material which can withstand millikelvin temperatures

without creeping, cracking, or releasing vapor, and the resistance thermometers used for ultralow temperatures are often made of treated graphite or germanium. The culmination of years of materials science research and careful engineering has produced instrumentation with the capability for precise measurements from temperatures down to the millikelvin level. There are four main systems that function to provide the proper conditions for measurement: the reservoir temperature control, the sample temperature control, the magnetic field control, and the pressure control system. The essential components of these systems will be discussed in more detail in the following sections with special emphasis on the cooling systems that allow these extreme low temperatures to be achieved.

Cooling systems

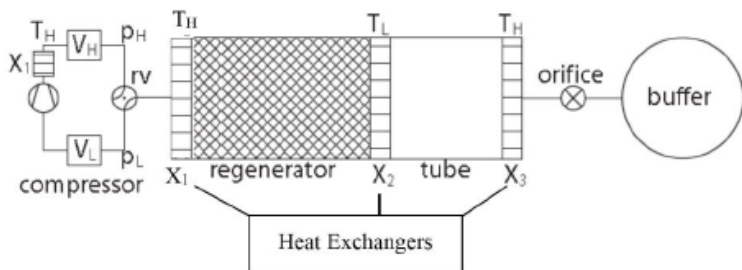
The first of these is responsible for maintaining the low baseline temperature to which the sample temperature relaxes. This is typically accomplished with the use of liquid helium cryostats or, in more recent years, so-called “cryogen-free” pulse tube coolers.

A cryostat is simply a bath of cryogenic fluid that is kept in thermal contact with the sample. The fluid bath may be static or may be pumped through a circulation system for better cooling. The cryostat

must also be thermally insulated from the external environment in order to maintain low temperatures. Insulation is provided by a metallic vacuum dewar: The vacuum virtually eliminates conductive or convective heat transfer from the environment and the reflective metallic outer sleeve acts as a radiation shield. For the low temperatures required to observe some magnetic transitions, liquid helium is generally required. ^4He liquefies at 4.2 K, and the rarer (and much more expensive) isotope, ^3He , liquefies at 1.8 K. For temperatures lower than 1.8 K, modern instruments employ evaporative attachments such as a 1-K pot, ^3He refrigerator, or a dilution refrigerator. The 1-K pot is so named because it can achieve temperatures down to 1 K. It consists of a small vessel filled with liquid ^4He under reduced pressure. Heat is absorbed as the liquid evaporates and is carried away by the vapor. The ^3He refrigerator utilizes a 1-K pot for liquefaction of ^3He , then evaporation of ^3He provide cooling to the sample. ^3He refrigerators can provide temperatures as low as 200 mK. The dilution refrigerator works on a similar principle, however the working fluid is a mixture of ^3He and ^4He . Phase separation of the ^3He from the mixture provides further heat absorption as the ^3He evaporates. Dilution refrigerators can achieve temperatures as low as 0.002 K (That's cold!). Evaporative refrigerators work only on a small area in thermal contact with the sample, rather than delivering cooling power to the entire volume of the cryostat bath.

Cryostat baths provide very high cooling power for very efficient cooling; however, they come with a major drawback: the cost of helium is prohibitively high. The helium vapor that boils off as it provides cooling to the sample must leave the system in order to carry the heat away and must therefore be replaced. Even when the instrument is not in use, there is some loss of helium due to the imperfect nature of the insulating dewars. In order to get the most use out of the helium, then, cryostat systems must always be in use. In addition, rather than allowing expensive helium to simply escape, recovery systems for helium exhaust must be installed in order to operate in a cost-effective manner, though these systems are not 100% efficient, and the cost of operation and maintenance of recovery systems is not small either. “Cryogen-free” coolers provide an alternative to cryostats in order to avoid the costs associated with helium usage and recovery.

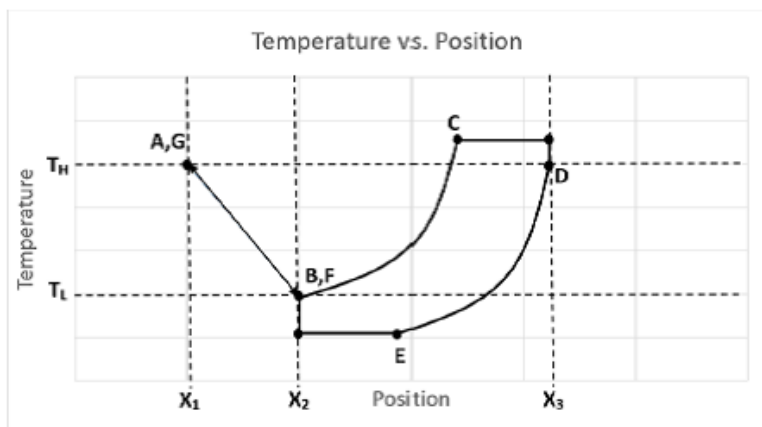
[\[link\]](#) shows a Gifford-McMahon type pulse tube—one example of the cryogen-free coolers.



In this type of cooler, helium gas is driven through

the regenerator by a compressor. As a small volume element of the gas passes through the regenerator, it drops in temperature as it deposits heat into the regenerator. The regenerator must have a high specific heat in order to effectively absorb energy from the helium gas. For higher-temperature pulse tube coolers, the regenerator is often made of copper mesh; however, for very low temperatures, helium has a higher specific heat than most metals. Regenerators for this temperature range are often made of porous rare earth ceramics with magnetic transitions in the low temperature range. The increase in specific heat near the Schottky anomaly for these materials provides the necessary capacity for heat absorption. As the gas enters the tube at a temperature T_L (from the diagram above) it is compressed, raising the temperature in accordance with the ideal gas law. At this point, the gas is at a temperature higher than T_H and excess heat is exhausted through the heat exchanger marked X_3 until the temperature is in equilibrium with T_H . When the rotary valve in the compressor turns, the expansion cycle begins, and the gas cools as it expands adiabatically to a temperature below T_L . It then absorbs heat from the sample through the heat exchanger X_2 . This step provides the cooling power in pulse tube coolers. Afterward, it travels back through the regenerator at a cold temperature and reabsorbs the heat that was initially stored during compression, and regains its original temperature through the heat exchanger X_1 . [\[link\]](#) illustrates the

temperature cycle experienced by a volume element of the working gas as it moves through the pulse tube.



Pulse tube coolers are not truly “cryogen-free” as they are advertised, but they are preferable to cryostats because there is no net loss of the helium in the system. However, pulse tubes are not a perfect solution. They have very low efficiency over large changes in temperature and at very low temperatures as given by [\[link\]](#).

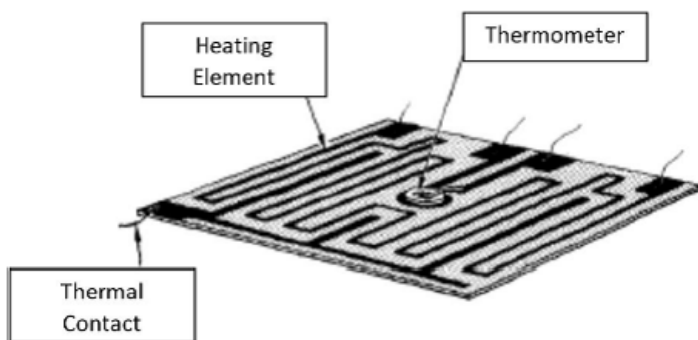
$$\xi = 1 - \Delta T / T_H$$

As a result, pulse tube coolers consume a lot of electricity to provide the necessary cooling and may take a long time to achieve the desired temperature. Over large temperature ranges such as the 4 – 300 K range typically used in specific heat measurements, pulse tubes can be used in stages, with one providing pre-cooling for the next, to increase the cooling power and provide a shorter cooling time,

though this tends to increase the energy consumption. The cost of running a pulse tube system is still generally less than that of a cryostat, however, and unlike cryostats, pulse tube systems do not have to be used constantly in order to remain cost-effective.

Sample conditions

While the cooling system works more or less independently, the other systems—the sample temperature control, the magnetic field control, and the pressure control systems—work together to create the proper conditions for measurement of the sample. The sample temperature control system provides the heat pulse used to increase the temperature of the sample before relaxation occurs. The components of this system are incorporated into the sapphire sample platform as shown in [\[link\]](#).



The sample is affixed to the platform over the thermometer with a small amount of grease, which

also provides thermal conductance between the heating element and the sample. The heat pulse is delivered to the sample by running a small current pulse through the heating element, and the response is measured by a resistance thermometer. The resistance thermometer is made of specially-treated carbon or germanium which have standardized resistances for given temperatures. The thermometer is calibrated to these standards to provide accurate temperature readings throughout the range of temperatures used for specific heat measurements. A conductive wire provides thermal connection between the sample platform and the heat reservoir. This wire must provide high conductivity to ensure that the heat transfer from the sample to the platform is the dominant process and prevent significant two- τ behavior. Sample preparation is also governed by the temperature control system. The sample must be in good thermal contact with the platform, therefore, a sample with a flat face is preferable. The volume of the sample cannot be too large, either, or the heating element will not be able to heat the sample uniformly. A temperature gradient throughout the sample skews the measurement of the temperature made by the thermometer. Moreover, it is impossible to assign a 1:1 correspondence between the specific heat and temperature if the specific heat values do not correspond to a singular temperature. For the best measurements, heat capacity samples must be cut from large single-crystals or polycrystalline solids

using a hard diamond saw to prevent contamination of the sample with foreign material.

The magnetic field control system provides magnetic fields ranging from 0 to >15 T. As was mentioned previously, strong magnetic fields can suppress the transition to magnetically ordered states to lower temperatures, which is important for studying quantum critical behaviors. The magnetic field control consists of a high-current solenoid and regulating electronics to ensure stable current and field outputs.

The pressure systems controls the pressure in the sample chamber, which is physically separated from the bath by a wall which allows thermal transfer only. While the sample is installed in the chamber, the vacuum system must be able to maintain low pressures ($\sim 10^{-5}$ torr) to ensure that no gas is present. If the vacuum system fails, water from any air present in the system can condense inside the sample chamber, including on the sample platform, which alters thermal conductance and throws off measurement of the specific heat. Moreover, as the temperature in the chamber drops, water can freeze and expand in the chamber which can cause significant damage to the instrument itself.

Conclusions

Through the application of specialized materials and technology, measurements of the specific heat have become both highly accurate and very precise. As our measurement capabilities expand toward the 0 K limit, exciting prospects arise for completion of our understanding, discovery of new phenomena, and development of important applications of novel magnetic materials. Specific heat measurements, then, are a vital tool for studying magnetic materials, whether as a means of exploring the strange phenomena of quantum physics such as quantum criticality or heavy fermions, or simply as a routine method of characterizing physical transitions between different states.

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